Master Thesis Report

FEASIBILITY AND MARKET ASSESSMENT FOR EV SCHEDULING AND AGGREGATION IN EUROPEAN COUNTRIES

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ABSTRACT

Energy system has been going through a revolutionary transformation over the past years. The rising adoption of unpredictable, decentralised renewable energy sources is said to accelerate in the next decades. Variable renewable electricity production in many different locations, can often lead to unexpected and unsought for deviations of gird parameters: frequency and voltage. unsought for deviations of gird parameters: frequency and voltage, or even congestion of the system. Thus, decentralised electricity system would have a surpassing need of flexibility of the system, which could assure proper regulation of frequency and voltage when needed.

The consumption of electricity is also viable and not utterly predictable. To avoid the congestion of electrical grid the demand side response concept has been sprouting. One of the new concepts of demand side response measures is aggregation. Aggregated load regulation envisions gathering and managing numerous small loads, in a way that could stop deviations of frequency and voltage in the system or avoid congestion, without bringing any inconveniences for the owner of the load. EVs while charging, are those loads that are often mentioned as aggragatable.

With the emerge of massive adoption of Electric Vehicle, secondary uses of it are being questioned. One of them is the idea of balancing the ever changing frequency and voltage in the grid with usage of flexibility created by creating various patterns of charging an electric vehicle. This process is known as Smart Charging.

This study integrates previously mentioned innovations of energy system and analyse the potential of aggregation of electric vehicles for the purpose of providing flexibility to the electricity system. The thesis will be a technical and economic analysis of the possibility of unlocking this potential in Europe.

The regulatory and technical aspects of possible demand side response aggregation development are presented in the thesis, along with the analysis of Electric Vehicles market and its potential.

Thereafter, one exemplary market is analysed further, through developed optimisation model, which allows to assess the value of most important factors for the aggregator. Three key changing variables are considered in the scheme of charge, those are: the targeted group of clients, the power of the used charger, and the scheme of charging. To assess the importance of those variables the stream of revenues as well as the environmental benefits in the form of potential CO_2 emissions savings are analysed against the variables.

The major aim and finding of this thesis is to answer the question whether it is plausible to profitably develop grid balancing with smart charging of electric vehicles in European Free Trade Association membership countries. The reader will only get to know the answer to that question after flicking through the pages of this paper.

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GLOSSARY

BNEF – Bloomberg New Energy Finance

BRP – Balancing Responsible Party

BSP – Balancing Service Provider

DSO – Distribution System Operator

DSR - Demand Side Response

EV – Electric Vehicle

EFTA – European Free Trade Association

kWh - kilowatt hour

MWh - megawatt hour

TSO – Transmission System Operator

TWh – terawatt hour

1. Introduction

Ongoing trend of decentralising energy systems is said to accelerate in the coming years. Variable renewable electricity production in many different locations, can often lead to unexpected and unsought for deviations of gird parameters: frequency and voltage, or even congestion of the system. Thus, decentralised electricity system would have a surpassing need of flexibility of the system, which could assure proper regulation of frequency and voltage when needed [1].

As digital and control technology has been advancing, the electricity system has been getting more decentralised and the demand side response concept has been sprouting, the new concept arisen, that is aggregated load. Aggregated load regulation envisions gathering and managing numerous small loads, in a way that could stop deviations of frequency and voltage in the system, without bringing any inconveniences for the owner of the load. Heat pumps and EVs while charging, are those loads that are often mentioned as aggragatable [2].

Another rapidly proceeding trend is the switch from combustion engine to an electric vehicle. EVs sales are said to surpass combustion engine vehicles sales as near as in the next two decades, making the electricity even more essential [3]. With the emerge of massive adoption of this technology, secondary uses of it are being questioned. One of them is the idea of balancing the ever changing frequency and voltage in the grid with usage of flexibility created by creating various patterns of charging an electric vehicle. This process is known as Smart Charging [4].

This study will integrate all of the previously mentioned innovations of energy system and analyse the potential of aggregation of electric vehicles for the purpose of providing flexibility to the electricity system. The thesis will be a technical and economic analysis of the possibility of unlocking this potential in Europe.

The study will first consider all European Free Trade Association Countries. The regulatory and technical analysis of possible demand response aggregation will then on eliminate some of the countries as not suitable for the development of EV aggregation yet, in term so of legality of demand side response and aggregation, as well as the technical requirements of specific markets which could be exceeding the limitations of electric vehicles aggregation.

Thereafter the remaining, promising markets, will be analysed even further. The electricity markets, along with ancillary services market evaluation will be extended by the analysis of electric vehicles market and development of EV infrastructure, mainly charging points, in certain, previously chosen, European countries.

Furthermore, for the markets showing the highest potential in the previous analysis, possible revenues per electric car will be estimated. The estimation will be done with usage of the historical data from the markets. Python algorithm scheduling the charging patterns and calculating the potential flexibility of EV fleet will estimate the profitability and environmental benefits of smart charging on the chosen markets. Various scenarios and patterns of charging will be considered and compared in the analysis, to see what would be to most important factor for a potential aggregator in relation to the potential client.

Conclusions of the analysis along with the choice of best approach of developing Smart Charging in Europe will be the final part of this investigation. Thus, the study would be a direction which one should follow during the implementation of so called smart charging in the current European electricity markets.

2. AIMS AND OBJECTIVES

Transformation of energy sector, although desired, comes with numerous diverse concerns. One of them, and one of most crucial, is the instability of fundamental parameters of the grid: frequency and voltage, as well as the maintenance of the congestion of the grid. Nevertheless, there are also innovative solutions for grid balancing. One of them is regulation of charging process of an electric vehicle, in order to balance the grid, so called Smart Charging.

This study will inspect, whether Smart Charging activity could arise in any of membership countries of the EFTA in terms of present regulations, technical feasibility and economic sensibility.

Moreover, the study will identify the potential of the future development of gird balancing with smart charging, favourable for an EV aggregator, changes in regulations and requirements of the EFTA wholesale energy markets and ancillary services.

Additionally, the study will answer the question as which current European market is most suitable for taking the lead in implementing grid balancing through Smart Charging.

Thus, the aims of this study are:

1. Comprehension of the current situation in the EU in terms of grid balancing with EVs.
2. Assessment of the economic and environmental potential of such solution.
3. Reaching the best strategy for implementation of grid balancing with EVs in European Free Trade Association membership countries.

Those aims would be achieved by following objectives, the objectives touch upon literature review with market analysis, research methodology (collection of data, creation of algorithm and market development projections), critical evaluation and recommendations.

1. Examination of European regulations and activity in aggregated load balancing and demand side response.
2. Investigation of the possible future changes in those regulations.
3. Analysis of electric vehicle development and infrastructure in European countries showing promising entry point for Smart Charging.
4. Collecting data on possible revenue streams for markets promising entry point markets.
5. Analysis of potential growth of electric vehicles sector in those markets, in terms of EV fleet and charging infrastructure.

6. Creation of the Python model allowing testing of various charging scenarios with implementation of previous regulatory constraints and market data, about demand and payments into the model.
7. Creation of scenarios worth analysing in the model.
8. Analysis of the scenarios, to develop the most optimal scenario of implementation of grid balancing with smart charging in regard to the potential target group.
9. Analysis of revenue streams per one electric vehicles for markets showing promising outcomes and for charging scenarios.
10. Analysis of the potential positive environmental impact of Smart Charging.
11. Recommendation of the best approach of grid balancing with EVs implementation in current European markets.
12. Conclusions on the nowadays implementation of grid balancing with aggregated EVs in terms of European regulations and technical requirements.

3. Assessment of possible development of grid balancing with EVs

In this chapter, the regulatory possibility of development of grid balancing with Smart Charging will be evaluated. Firstly, all European Free Trade Association countries will be considered, against given criteria. Then on, in countries showing a regulatory and technical possibility of gird balancing with EVs, the economic study of ancillary services and energy markets will be conducted.

The criteria against which ancillary services and wholesale energy markets will be analysed are as follows,

1. Visible activity in Demand Side Response. Grid balancing with aggregated electric vehicles is an example of demand side response action. Thus, demand side response activities must be visible on a targeted market.
2. Legality of aggregation. As gird balancing with electric vehicles, would require aggregating a meaningful load out of a larger pool of vehicles, thus load aggregation must be legal.
3. Regulatory Constraints. Even with legal demand side response and aggregation, the regulatory constraints might be too troublesome to enter the market. The last criteria for further evaluation is lack of regulatory boundaries.

Previously presented criteria will allow to narrow down the pool of considered countries. If the country is showing potential, against the criteria, it will be further analysed.

Next step of analysis will assess ancillary services and energy markets in the context of grid balancing with electric vehicles. First, and foremost the legality of aggregated demand response will be analysed for each service, as often various rules concern different services.

For remaining markets, in which aggregated demand response is allowed, requirements to enter the markets will be analysed, as they can often create a technical constraint for Smart Charging balancing.

Furthermore, the brief analysis of all markets will be created, determining the market size and average payments (both utilisation and availability) and annual market revenues. Additionally, the structure of demand side response markets will be presented for each country along with a competition intensity and market saturation analysis.

Ultimately, after a thorough analysis of all previously mentioned information, an assessment whether the country is a theoretically promising entry point for grid balancing with electric vehicles smart charging will be determined.

3.1 Assessment of Demand Side Response activity

As grid balancing with smart charging of electric vehicles is an expression of demand side response, the market in which the idea could be developed should be familiar with demand side response activities. To assess whether any DSR activity is visible on the market, three criteria must be fulfilled. Those are: demand side response must be defined and legal in a regulatory framework, there are ongoing pilot projects, or the pilot project phase of implementation is already completed, and there are programs promoting DSR.

The following Figure 1, illustrating the current state of activity in demand side response, is the outcome of analysis of reports portraying the current state of implementation of demand side response [5] [6].

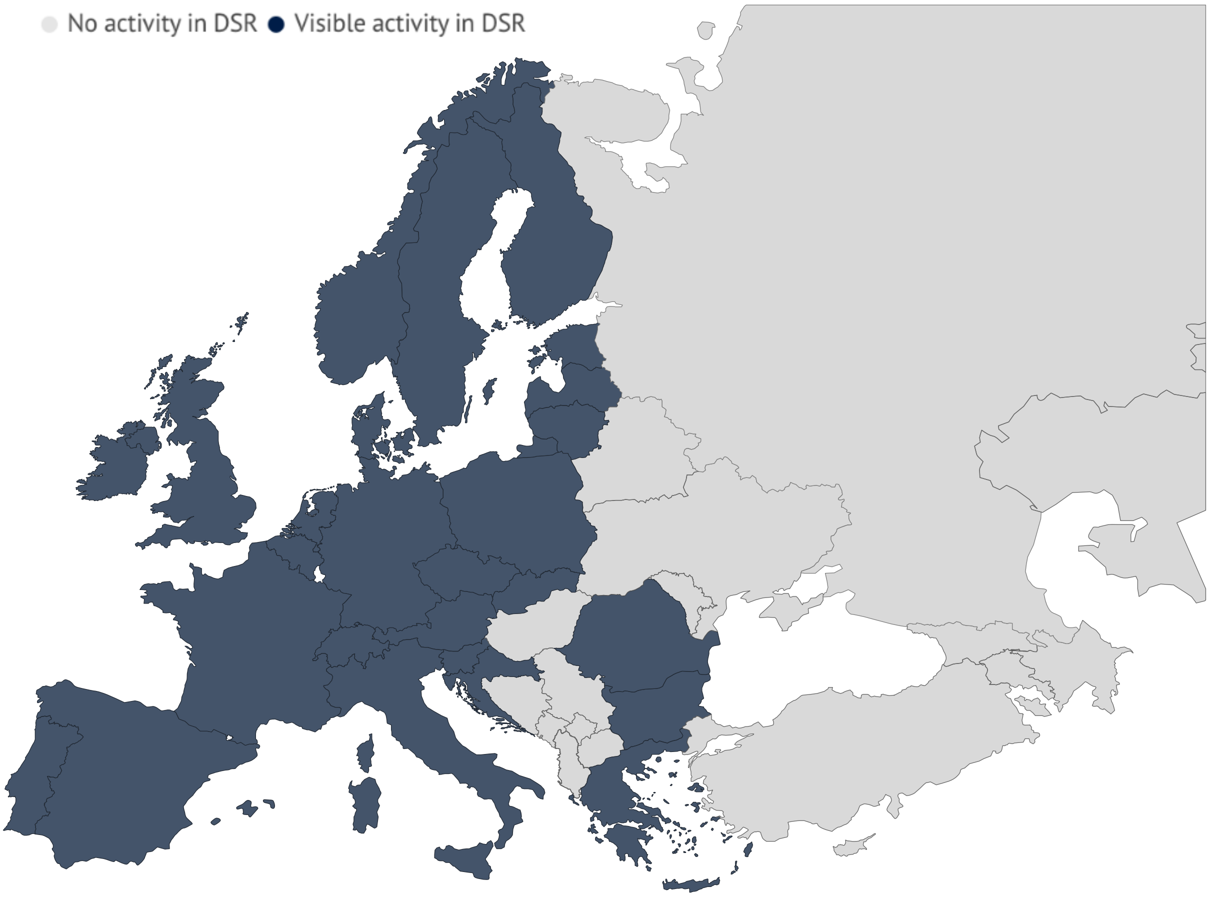


Figure 1 Illustrative map showing DSR activity in EFTA member states.

The map clearly shows, that almost EFTA member states countries show visible DSR potential, with except of few Balkan countries (Bosnia and Herzegovina, Serbia and Kosovo, Montenegro, Albania, Macedonia and Hungary), which won't be considered further in this study, as right markets to develop grid balancing with smart charging of electric vehicles.

3.2 Assessment of legality of aggregation

Another major criteria shaping decision of grid balancing with electric vehicles development is legality of aggregation. Electric load aggregation means gathering more than one electric load and controlling them in a desired way, by either reducing the load or increasing it basing on the needs of electrical grid or current electricity prices.

The concept of demand side response with aggregated load, would be considered legal on a certain market if two criteria is fulfilled: the concept of load aggregation is defined within the legal framework of the country and, that it is allowed.

The following Figure 2, illustrating the current state of legality of aggregation, is the outcome of analysis of reports portraying the current state of implementation of aggregated load demand side response [5] [6].

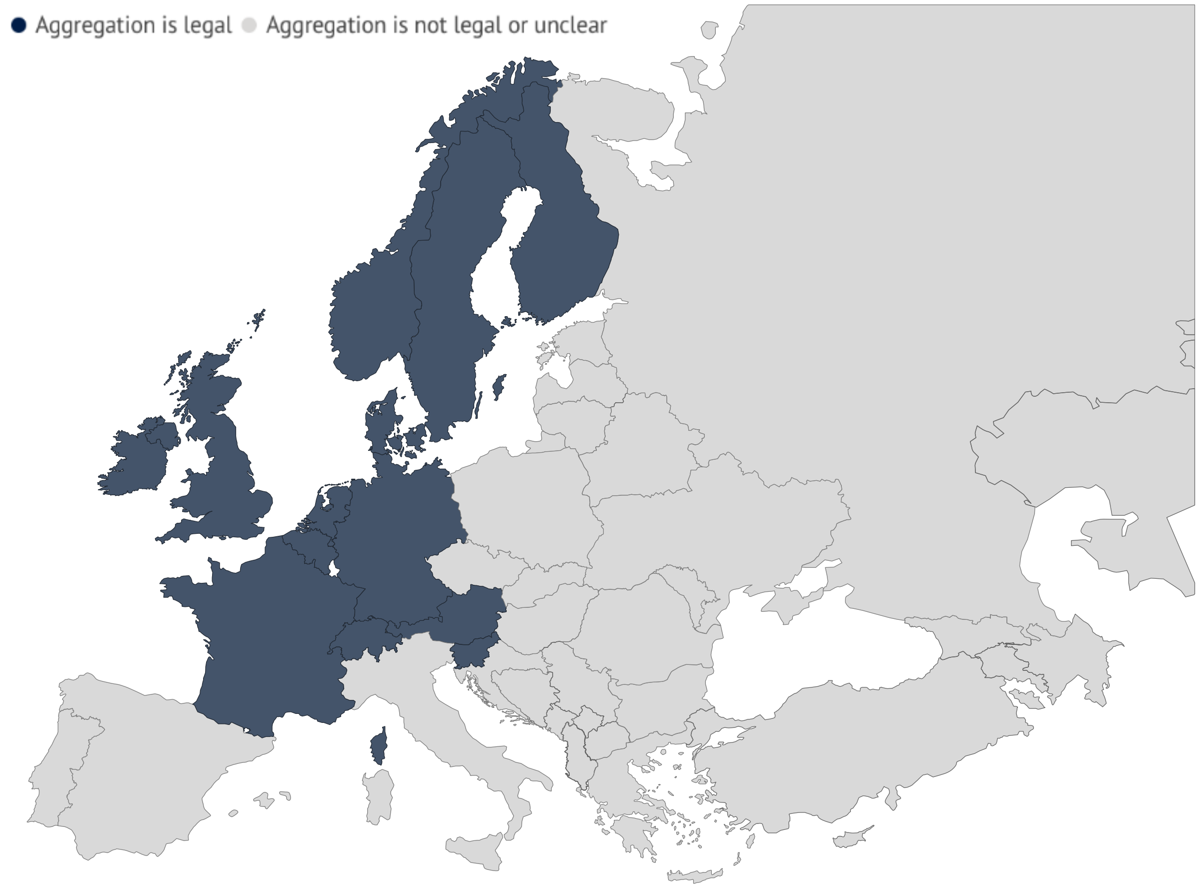


Figure 2 Map illustrating legality of aggregation within EFTA member states

This illustration, clearly states that whereas DSR might be already adapted technology, aggregated load is not. There are just eleven countries in which aggregating an electric load is defined and allowed, those are: Finland, Sweden, Norway, Denmark, Germany, the Netherlands, Belgium, France, Switzerland, Austria and Slovenia. The implementation of aggregating electric vehicles to balance the grid from now on will be analysed in those countries.

3.3 Assessment of regulatory constraints

Nevertheless, even if DSR activities are visible and if aggregation is legal, grid balancing could still be problematic to develop, because of existing regulatory constraints. Those constraints, touch upon who is allowed to aggregate loads.

Some of the legal framework concerning aggregation, specifies that only an energy retailer could be an aggregator. The complexity of entering the market as an energy retailer, is considered enough to eliminate all countries that give this requirement to the aggregator.

Another often found requirement is for an aggregator to have a bilateral contract with clients' BRP. As this requirement implies legal complexity for the aggregator and for his client this constraint is also treated as a boundary to enter the market.

Thusly, only the markets on which an independent third party aggregation is allowed will be considered as markets favourable for grid balancing with electric vehicles smart charging.

The following Figure 3, illustrating the current state of regulatory constraints for aggregators, is the outcome of analysis of reports portraying the current state of legal framework concerning the role of aggregator on the market [5] [6].

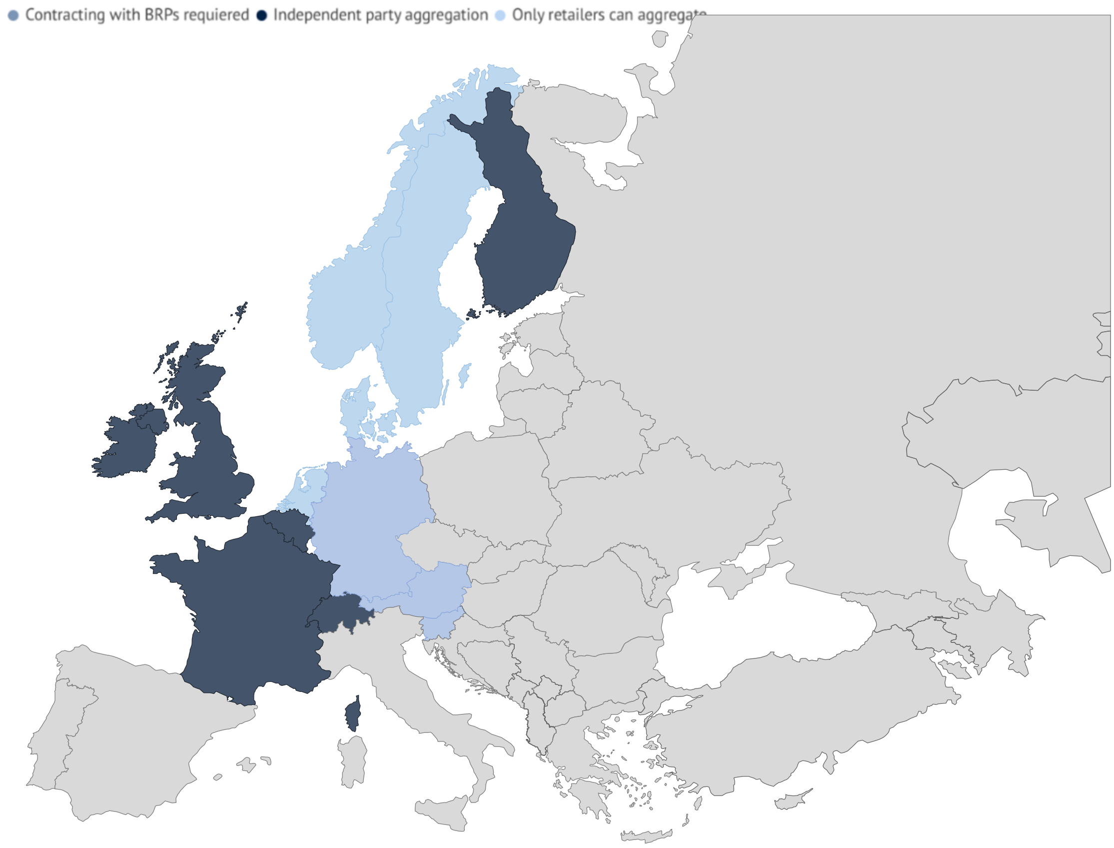


Figure 3 Map illustrating the regulatory constraints for aggregation within EFTA member states

As previously mentioned, requirements for an aggregator to be a retailer or to contract clients' BRPs creates to much complexity, so this study will consider that only third party independent aggregation is a good point of entry to the market.

Independent aggregation is allowed in six of remaining EFTA membership countries, those are: Belgium, Finland, France, Ireland, United Kingdom and Switzerland. Concluding the findings of the first tested criteria, only those countries will be analysed further in this study, as possible to successfully develop grid balancing with smart charging of aggregated electric vehicles.

3.4 Market evaluation

Previous fragment allowed to already establish which countries could be further analysed. In this section however, the markets available in those countries will be evaluated more deeply. Electricity markets that will be studied are ancillary services and wholesale electricity market. At first, a deeper look into legality of demands side response and aggregation will be taken, as those aspects could be legal on only some of the markets.

Thereafter, once all markets that could be balanced with electric vehicles smart charging are recognized an examination of technical requirements will be put in place. Technical requirements could further disqualify some of markets or services, as load aggregated from electric vehicles has clear size and availability limits.

Requirements that will be considered as favourable in development of grid balancing with electric vehicles smart charging are as follows:

- Minimal bid of no less than 5 MW, with preferred smaller values; Aggregating a load of 5 MW could already require an out-of-reach number of vehicles, which is problematic for an entry point [7].
- There are no constraints regarding the minimal single load; If constraints about minimal single load exist they usually specify that load should not be smaller than 0,1 MW or even 1 MW which is not the case for smart charging of an electric vehicle.
- Minimal availability time of no more than 4 hours; It cannot be expected that grid balancing with electric vehicles could be delivered constantly at the same level, as EV owners are using their vehicles, and the service is provided only during battery charging. Therefore, there is constraint regarding maximal availability time required, it has been set to 4 hours.
- Tender period, if applicable, of no more than 4 hours, tender period in some cases could express required availability time, therefore it has also been set up to 4 hours.
- Response time no lesser than 5 seconds; The time that a load aggregated from the pool of vehicles needs to response to a control signal [8].

Subsequently, remaining markets will be a part of ongoing analysis. For that, market sizes along with possible utilisation and activation prices, if applicable, will be presented alongside with revenue of market/service. Additionally, a brief review of competition intensity, market saturation and market structure will be done for each country showing promise of successful market entry.

3.4.1 Belgium

Technical Requirements

To properly assess the potential of entering Belgian energy market with the idea to balance the gird with electric vehicles, one should firstly evaluate which markets allow aggregation and demand side response.

Aggregation is not legal at all on the wholesale electricity market in Belgium. Regarding ancillary services market, demand side response and aggregation are only legal on following markets: Primary frequency Control (R1 Load-Up), Tertiary Frequency Control R3-DP, Tertiary Frequency Control R3 ICH, Strategic Reserve SDR [5]. Thus, only those markets will be further analysed.

The following Table 1 is a summary of all technical constraints required by Elia (Belgian TSO), in order to access those ancillary services [5] [9].

Table 1 Technical Requirements for an Aggregator in Belgian ancillary services

	R1–Load Up	R3 DP	R3 ICH	SDR
Minimal Bid	1 MW	1MW	1 MW	1MW
Availability time	min 15 min	Max 2 hours	Max 4/8/12 h	max 250h
Minimal time between two interruptions	–	12 h	24 h	600 h
Notification Time	30s	15 min	3 min	6,5h
Tender period	14 days said to go down to 4h	14 days	14 days said to go down to 4 hours	14 days said to go down to 4h
Assessment	Feasible	Unfeasible	Feasible	Feasible

Additionally, some of the services have a requirement concerning maximal cumulated activation time throughout one year. Those obligations are as follows, for SDR maximal activation time is 130 hours in winters and R3 ICH could only be activated 4 times a year [5].

Although, R3 ICH follows through on all previously mentioned constraints, it is currently being phased out and therefore, has been assessed as not a promising entry market [5].

Finally, the evaluation of ancillary services market in Belgium, has showed that possible entry markets are R1 Load Up and SDR, however only provided that the tender period will be shortened to 4 hours, which Elia has expressed interest in [7].

Belgian ancillary services market review

Market Sizing

The Table 2 hereunder presents the markets size, average availability payment, average utilization payment, how often the service is triggered per year and yearly revenues available on the market. The revenues were calculated basing on the market behaviour in 2017 published by Belgian TSO- Elia [10].

Table 2 Market Sizing of available Belgian ancillary services

	R1–Load Up	R3 DP	SDR
Market Size	27 MW	60 MW	97 MW
Availability payments [€/MW/h]	5–6	3,07 €	Not public
Utilization payments [€/MWh]	None	None	65
Triggered per year	70 min	40 times per year	20 times per year
Market Revenue	1 350 000 €	150 637 067 €	Data not public

As visible the R3 DP market revenues per year are significantly higher to those of R1 Load Up. However, those revenues represent the total market value of 60 MW in tertiary reserve, as data for R3 DP was not available. The data for strategic reserve is not published, and therefore inaccessible.

Market Saturation

Market of ancillary services is regulated with fixed demand, therefore one only produces as much flexibility as is demanded by the grid. In that case market could become oversaturated, leading to lower revenues for the players. However, saturation of aggregator demand side response market is not expected as it is still an innovative way of trading.

Currently on the Belgian ancillary services market, only 25% of capacity could be realised with aggregated demand side response load [5] [9]. That flexibility is created by twelve aggregators playing on tertiary response market. Out of those twelve aggregators nine also play on R1 Load Up market [9].

Demand Side Response, could be divided into three categories: industrial, commercial and residential, depending on a source of flexibility. Belgian market illustrates the general trend in demand side response. Firstly, only the potential of industrial demand response has been tapped, as all the aggregators are targeting industrial clients [11]. Secondly, commercial aggregation is somewhat present, but the potential is not fully harnessed as only 2 aggregators target large commercial clients, those are: Restore and Electrabel owned by Engie [12] [13]. Thirdly, the residential aggregation potential is completely untapped, as there is no aggregator in Belgium playing with flexibility of residential customers.

Current market structure, however, is not a reflection of the potential that demand side response creates, according to the report created by SiaPartners, only in Belgium demand side response potential could be as high as 799 TWh annually, out of which less than one third is harnessed currently [14]. The structure of demand side response potential in Belgium is as presented on the following Figure 4 [14]

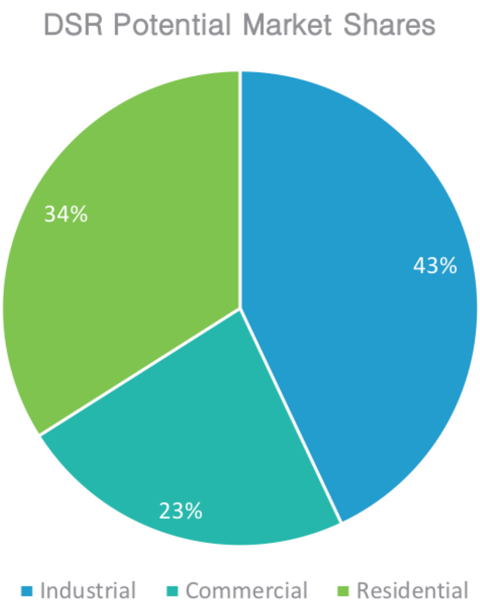


Figure 4 Structure of potential of Demand Side Response in Belgium

As illustrated above, residential DSR represents over thirty percent of the potential of DSR in Belgium.

As only one third of potential of demands side response is currently tapped, and only 25% of capacity required by ancillary services is allowed to be covered by DSR, it could be stated that the market Belgian market is nowhere close to being saturated yet.

Furthermore, the current structure of aggregation, along the potential of demand side response show that market of residential and commercial aggregated demand side response is still a non-competitive market.

In conclusion Belgian market, with low competition and low level of saturation, shows a promising entry point, provided that the tender period of R1 Load Up and R3 DP services would be shortened up to four hours.

3.4.2 Finland

Technical requirements

To properly assess the potential of entering Finish energy market with service balancing the gird through electric vehicles, one should firstly evaluate which markets allow participation of aggregated demand response.

Aggregated demand response is currently allowed only through one ancillary service: frequency containment reserve for disturbances (FCR-D), the technical requirements for market entry are presented in Table 3 hereunder [5] [15].

Table 3 Technical requirements for market participation in Finland

	FCR-D
Minimal Bid	1 MW
Availability time	Usually during the tender period
Notification Time	5s
Tender Period	1 year
Assessment	Feasible but unlikely

The table gives a short summary of technical requirements created by Ingrid (Finish TSO), as the tender period is one year and constant availability is usually required from aggregators, the one available market is not accessible for electric vehicle balancing mechanism. However, during contacting with Fingrid the availability time could be individually discussed and agreed upon by both sides.

Aggregated demand response is also allowed on wholesale energy market, however the aggregator must register as a BRP. That option has not been considered, as to register as a BRP in Finland, one should place 200 000 € of deposit, in case of sudden bankruptcy and is therefore out of reach for an entry market [5]. Thus, wholesale energy market was decided as inaccessible for an innovative load aggregator.

Finish wholesale and ancillary services market review

Market Sizing

Table 4 hereunder presents the markets size in volume, average availability payment, average utilization payment, and yearly revenues available on the market. Those are calculated basing on the market behaviour in 2017 published by Finish TSO- FinGrid [16].

Table 4 Market Sizing of available Finish market entry points

	FCR-D
Market Size	240 MW
Availability payments [€/MW/h]	3,39
Utilization payments [€/MWh]	None
Triggered per year	Several times a day
Market Revenue	**267 267 €**

The table gives a short summary of the market available for aggregated demand side response. The reader would be able observe that currently approachable Finish market is significantly smaller than Belgian markets presented beforehand.

Market Saturation

Aggregated demand side response is allowed on allowed only on 50% of capacity contracted by frequency containment reserve for disturbances [15]. Consequently, aggregated demand response as for now can access only 23% of all ancillary services markets available in Finland.

Demand Side Response and aggregation are still in a pilot project phase in Finland, as markets are not yet fully developed [17]. Moreover, Fingird does not publish data on demand side response aggregators playing on FCR-D market, although it is assumed that the current structure of the market is similar to the overall European trend, with mostly industrial demand side response present.

Nevertheless, there is a promising structure of DSR potential in Finland (with residential DSR showing most potential) [18]. That structure is presented on Figure 5 hereunder.

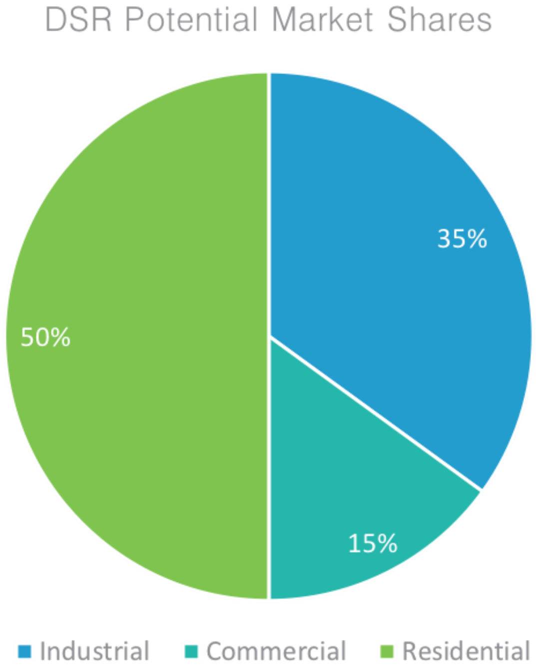


Figure 5 Structure of potential of Demand Side Response in Finland

Nonetheless, considering that only one service is allowing demand side response aggregation, as well as difficulties in contracting this service, Finland is not considered to be a valid entry point for grid balancing with smart charging.

However, there are currently ongoing pilot projects (on aFRR and FCR-N ancillary services) with regard to allowance of demand side response aggregation on other ancillary services. The market evaluation should be revisited once the regulatory framework is updated after the finalization of the pilot project [5] [17].

Furthermore, the Nordic markets have had a long term desire to unify their regulations [5] [19]. Thus, if the pilot projects in Finland end successfully aggregated demand side response could be more widely allowed also on Swedish, Norwegian and Danish markets.

3.4.3 France

Technical requirements

To properly assess the potential of entering French energy market with service balancing the gird through electric vehicles smart charging, one should firstly evaluate which markets allow participation of aggregated demand response.

To start with, aggregation and demand side response are legal on French electricity wholesale market, through NEBEF mechanism [20]. Moreover, aggregated demands response is also legal on almost all of the ancillary services offered by RTE, French TSO (excluding secondary reserve aFRR) [5]. However, the technical requirements often surpass capabilities of a load aggregated from electric vehicles.

As previously mentioned, even though all markets are open for aggregated demand response participation, the technical requirements could still create a meaningful entry barrier for EVs aggregator. Participation in fast reserve (mFRR) and complementary reserves (RR) is limited twofold by the high level of minimal bid and by the fact of constant availability for the tender period (weekly) [5].

Another service unavailable to grid balancing with EVs Smart Charging is Demand Response Call for Tenders (DSR-RR), in which participation could be problematic, due to extensive requirements for the availability time [5].

Capacity mechanism, in theory would be a perfect market for gird balancing with EVs, as an aggregator can choose preferable notices. However, an aggregator is allowed to play on capacity market only if all singular, individual loads are not smaller than 1 MW, which is unreachable while aggregating electric vehicles [21].

The review of technical requirements set by RTE is presented in Table 5 hereunder [5] [6] [21].

Table 5 Technical requirements for market participation in France

	NEBEF Day Ahead	NEBEF Intraday	FCR	mFRR	RR	DSR-RR	Capacity mechanism
Minimal bid	0,1 MW	0,1 MW	1 MW	10 MW		1 MW	1 MW (Individual power of at least 1 MW)
Availability time	Established in the contractual terms		During tender period, Symmetrical	During tender period	During tender period	Daily 06:00–20:00	Assessed noticewise
Notification time	24 h	4 h	30 s	13 min	30 min	2 h	–
Tender period	–	–	7 days, said to go down to 4 h	7 days	7 days	7 days	–
Assessment	Feasible	Feasible	Feasible	Unfeasible	Unfeasible	Unfeasible	Unfeasible

ETSEIB

Consequently, the markets that remain a possible entry point in France are: wholesale electricity market, through NEBEF mechanism (both intraday and day ahead) and primary frequency reserve (FCR), provided that the tender period will be shortened up to four hours, in which RTE expressed interest in [7].

French wholesale and ancillary services market review

Market Sizing

Table 6 hereunder presents the markets size in volume, average availability payment, average utilization payment, and yearly revenues available on the market. Revenues were calculated basing on the market behaviour in 2017 published by French TSO- RTE [22] [23].

Table 6 Market Sizing of available French market entry points

<table>
<tr><th></th><th>NEBEF
Day Ahead</th><th>NEBEF
Intraday</th><th>FCR</th></tr>
<tr><td>Market Size</td><td>10 GWh</td><td>0,6 GWh</td><td>1400 MW</td></tr>
<tr><td>Availability payments [€/MW/h]</td><td rowspan="2">43,58 (dependant on a tariff)</td><td rowspan="2">43,58 (dependant on a tariff)</td><td>7,42</td></tr>
<tr><td>Utilization payments [€/MWh]</td><td>44,29</td></tr>
<tr><td>Triggered per year</td><td>Several times a day</td><td>Several times a day</td><td>Continuously</td></tr>
<tr><td>Market Revenue</td><td colspan="2">1 540 900€</td><td>30 000 000€</td></tr>
</table>

Primary reserve ancillary service market is significantly bigger than the wholesale electricity market available for demand side response, through NEBEF mechanism, however an aggregator is not limited to playing only on one market. Thus, entering both of those markets could be a good entry point for an aggregator, provided that the tender period for FCR will be shortened to 4 hours, in which RTE expressed interest.

Market Saturation

Aggregated demand side response is allowed to participate on almost all markets in France. However, it does not necessarily mean that the market is already saturated. Aggregated demand response, traded through NEBEF adds up to less than 0,01% of energy traded on wholesale market in France [22]. Furthermore, aggregated demand response is allowed to participate on 42% of capacity demanded by French ancillary services and adds up to 3% of energy traded on French capacity mechanism [24] [5]. Those numbers, reflect the state of saturation of the market, in which the potential share of demand side response shows more promising results [18].

France is one of the leading regions regarding legislative and regulatory allowance of aggregated demand response [5], thus a significant number of aggregators playing on French markets is not surprising. There are currently, ten aggregators balancing the gird through primary reserve out of eleven players. The share of aggregation among NEBEF players is over 80%, that is eighteen aggregators out of twenty-two players [25] [26]. There are six aggregators who simultaneously play on both markets: FCR and NEBEF. Concluding there are currently twenty-two aggregators playing on FCR and NEBEF markets, with six of them playing on both markets.

The portfolio of an average French aggregator is no different than a portfolio of an average Belgian aggregator. Similarly, to Belgium in France aggregators tend to target industrial plants as their main clients. Out of twenty-two NEBEF and FCR demand side response aggregators, fourteen have only industrial clients. Moreover, there are three aggregators with both industrial and commercial clients. Additionally, there are three aggregators focusing on commercial and residential demand response: Voltalis, Energy Pool Development and Alpiq Energie France, as well as two aggregators focusing on as well industrial as commercial and residential demand response: Direct Energie SA and Equinov Demand Side Management [27] [28] [29] [30] [31].

Reflecting, upon the structure of the market, the dominance of industrial demand response is still significant, but with more market opportunities and looser technical requirements more commercial and residential demand response aggregators can safely enter the market.

Nevertheless, currently only industrial demand side response potential is being significantly harvested, with commercial and residential demand side response still developing. The structure of potential of DSR in France is presented on Figure 6 hereunder [18].

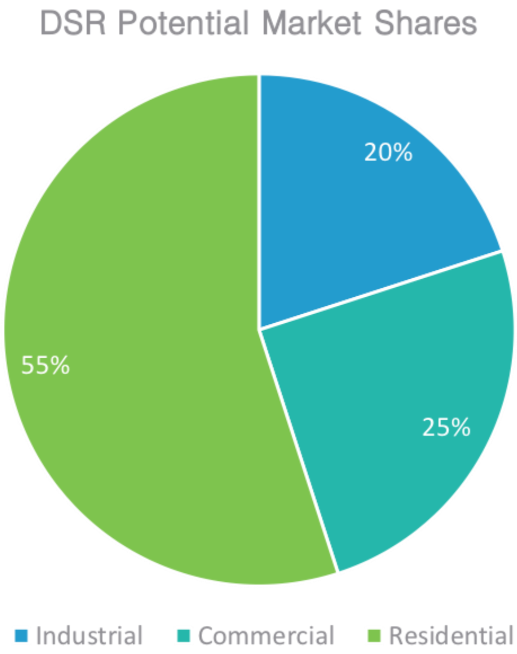


Figure 6 Structure of potential of Demand Side Response in France

As stated on the graph above, already tapped into industrial demand response, represents only 20% of overall demand side response potential in France. Furthermore, looking at the previously mentioned low share of demand side response in overall energy trading, on both capacity market as wholesale market, a claim could be made that French demand side response market is not yet saturated.

Furthermore, the current structure of aggregation, along the potential of demand side response show that market of residential and commercial aggregated demand side response is still a non-competitive market.

In conclusion French FCR and NEBEF mechanism markets, with rather low competition and low level of saturation, show a promising entry point, provided that the tender period of FCR services would be shortened up to four hours.

3.4.4 Ireland

Technical requirements

Aggregated demand side response is currently allowed only through interruptible load mechanism: STAR and price based capacity provision DSU [5]. However, the structure of wholesale electricity market along with ancillary services is about to undergo a complete and overall transformation [32].

Therefore, the technical requirements will not be presented, as the current requirements will not be valid soon, and the potential new requirements are unknown.

Irish wholesale and ancillary services market review

Market Sizing

The sizes of the potential markets are unknown, as the whole structure of the market is going to undergo a transformation.

Market Saturation

The structure of the whole energy market is going to change soon, however aggregated demand side response is already present on Irish market. Irish aggregated demand side response market is following the trends visible on all European markets: the major share of the market is taken by industrial demand response following by a small share of commercial demand side response and a non-existent residential demand side response. There are currently 7 aggregators registered on the price based capacity provision market, aggregating from 26 demand side units. Out of those units 82% are industrial and 18% commercial. There is currently no residential demands side response unit registered on an Irish market [33].

Nevertheless, the structure of potential of Irish demand side response reflects an utterly different market structure [18]. This potential is presented on Figure 7 hereunder.

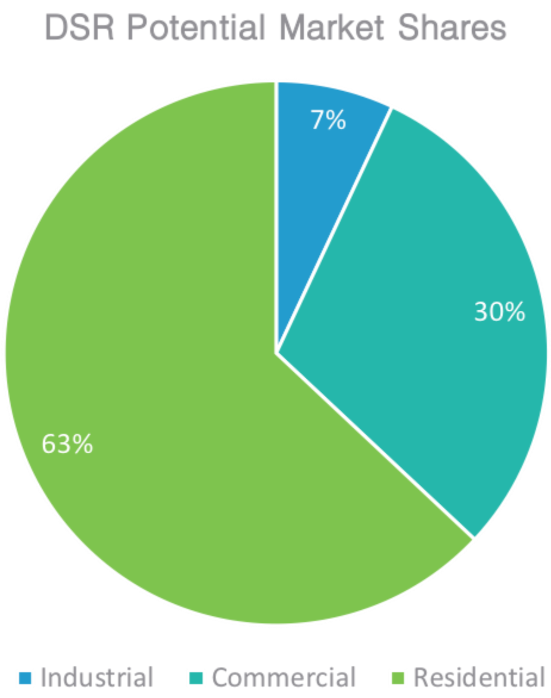


Figure 7 Structure of potential of Demand Side Response in Ireland

The regulations concerning the future of aggregated demand side response are still not certain, however it is predicted to be allowed on more markets, including the wholesale electricity market. Consequently, the market of today will not be analysed as a potential entry point for grid balancing with aggregated electric vehicles, however it is advised to revisit the idea of treating Ireland as a good entry point as soon as new regulations are public and in place. Ireland would seem to be becoming a promising entry point for EV grid balancing due to potential favourable regulations and lack of competition in the field of residential demand side response.

3.4.5 Switzerland

Technical requirements

To properly assess the potential of entering Swiss energy markets with service balancing the gird through electric vehicles smart charging, one should firstly evaluate which markets allow participation of aggregated demand response.

To start with, aggregation and demand side response are legal on Swiss electricity wholesale market [5]. Moreover, aggregated demands response is also legal on all of the balancing markets offered by SwissGrid, Swiss TSO [34].

Even though all markets are open for aggregated demand response participation, the technical requirements are still a meaningful entry barrier for EVs aggregator. Participation in primary reserve (FCR) is limited by extensive availability requirements, as market participant should be available always throughout the tender period, which lasts a week [34].

Another service unavailable to grid balancing with EVs smart charging is the secondary reserve (FFR), in which participation could be problematic, due to extensive requirements for the availability time (throughout the weekly tender period) as well as high requirements regarding the minimal bid (5 MW) [34]. As one of the services providing tertiary reserve has the same technical requirement, it is also unfeasible to play on this market (RR Weekly) [34].

Wholesale electricity market, in theory would be a perfect market for gird balancing with EVs, as an aggregator can choose preferable timeframes of operation. However, an aggregator is allowed to play on wholesale electricity market only after successful registration as a balancing serving party [5]. After that registration the aggregator is required to contract the BRP of each of its clients. That could prove problematic with a large pool of clients needed to aggregate a significant load from EVs.

The review of technical requirements set by SwissGrid is presented in Table 7 hereunder [5] [6] [34].

Table 7 Technical requirements for market participation in Switzerland

	Day Ahead	Intraday	FCR	FFR	RR Weekly +	RR Weekly –	RR Daily +	RR Daily –
Minimal Bid	0.1 MW	0.1 MW	1 MW	5 MW	5 MW		5 MW	
Availability time	–	–	During tender period	During tender period	During tender period		4h (6 time blocks of 4 hours)	
Notification Time	–	1h/15 min	30s	200s	15min	20–35 min	15 min	
Tender periods	–	–	1 week	1 week	1 Week		1 day	
Assessment	Unfeasible	Unfeasible	Unfeasible	Unfeasible	Unfeasible		Feasible	

Consequently, there is only one market remaining as a possible entry point, for grid balancing with aggregated EVs, in Switzerland: daily tertiary reserve balancing mechanism (RR Daily), both negative and positive.

Swiss wholesale and ancillary services market review

Market Sizing

Table 8 hereunder presents the feasible entry markets size in volume, average availability payment, average utilization payment, and yearly revenues available on the market. Those are calculated basing on the market behaviour in 2017 published by SwissGrid [35].

Table 8 Market Sizing of available Swiss market entry points

	RR Daily +	RR Daily –
Market Size	433.58 MW	258.55 MW
Availability payments [€/MW/h]	2.60 CHF	2.18 CHF
Utilization payments [€/MWh]	95 CHF	55 CHF
Triggered per year	16% of the time	
Market Revenue	CHF 3 408 530	CHF 1 955 420

The sizes of those markets are the reflection of the amount of time they are activated, as positive RR Daily is only activated 19% time of the year, whereas the negative RR Daily is active during 13% of the year [35].

Market Saturation

Aggregated demand side response is allowed to participate on all markets in Switzerland, both wholesale and ancillary services. However, that does not necessarily mean that the market is already saturated. Aggregated demand response, traded through wholesale electricity market adds up to less than 0,01% of energy traded on wholesale market in Switzerland [35].

Furthermore, aggregated demand response is allowed to participate on 100% of capacity demanded by Swiss ancillary services, however the amount of balancing done my demand side response is not public [5]. Nevertheless, the overall European trend shows that demand side response markets are not saturated yet, and the same assumption is made for the Swiss energy market [18].

Switzerland is one of the leading regions regarding legislative and regulatory allowance of aggregated demand response [5], thus a significant number of aggregators playing on Swiss markets is not surprising. The share of aggregators among Swiss ancillary services players is nearly 80%, that is nineteen aggregators out of twenty-five players. There are currently, fifteen aggregators balancing the gird through tertiary reserve out of nineteen players [36].

The portfolio of an average Swiss aggregator is not much different than a portfolio of an average European aggregator presented beforehand. Similarly, to Belgian and French aggregators, a Swiss one tends to target industrial plants as their main clients. Out of fifteen aggregators contributing to tertiary reserve, as much as ten have only industrial clients. Moreover, there are two more aggregators with both industrial and commercial clients.

Even if, commercial and residential demand side response is already present on Swiss balancing mechanism market. There are currently two aggregators targeting residential and commercial as well as industrial clients: EnergiePool and IWB [37] [38]. Furthermore, there is one particular aggregator worth looking into, Tiko or Swisscom Energy Solutions, is successfully targeting strictly residential and commercial demand response, mainly in form of battery storage, heat pumps and HVAC systems. As of today Swisscom Energy Solutions has already contracted over 10 000 residential customers and plays an important role on Swiss market of balancing mechanism being a part of primary, secondary and tertiary control reserve. [39]

Conversely, Tiko, even though focused on residential response, should not be considered as a first priority competitor, as the appliances targeted for aggregation are different. Currently Swisscom Energy Solutions has not expressed interest in electric vehicle aggregation.

Reflecting, upon the current market structure, the dominance of industrial demand response is still significant, but with more market opportunities and looser technical requirements more commercial and residential demand response aggregators would be able to easily enter the market. Nevertheless, as of now only industrial demand side response potential is being significantly harvested, with commercial and residential demand side response still developing.

The structure of potential of DSR in Switzerland is presented on Figure 8 hereunder [18].

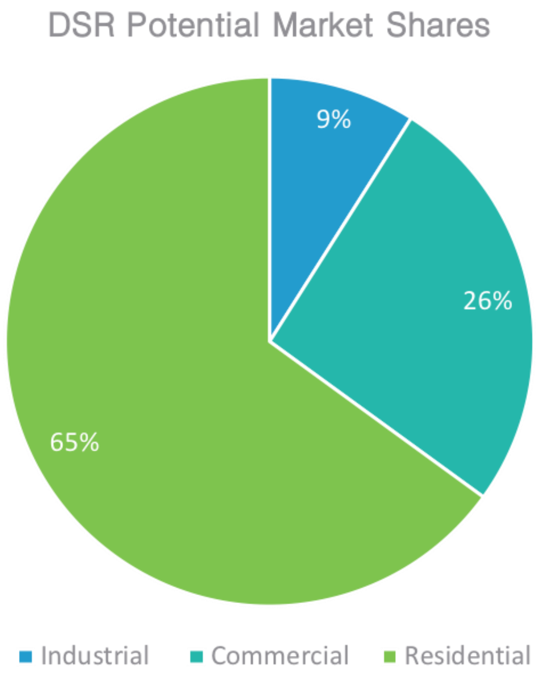


Figure 8 Structure of potential of Demand Side Response in Switzerland source (Demand response in Europe)

As stated on the graph above, already tapped into industrial demand response, represents only 26% of overall demand side response potential in Switzerland. Whereas, the remaining percentage is considered almost not harvested, as too few commercial and residential DSR players present on the market.

Furthermore, a study made by Paul Scherrer Institute, the overall potential of transportation demand side response, in line with New Energy Policy would be 6,14 TWh, which is 48% of total shift-able load (12 TWh) and almost 10% of predicted electricity consumption (51 TWh) [40].

In conclusion Swiss RR Daily tertiary reserve markets, with rather low competition and low level of saturation and high estimated potential of transportation demand side response, show a promising entry point. However, the high level of minimal bid (5 MW) might be a factor stopping an aggregator from entering the market as of right now, due to the still too low penetration of electric vehicles.

3.4.6 United Kingdom

Technical Requirements

To properly assess the potential of entering British energy market with service balancing the gird through electric vehicles, one should firstly evaluate which markets allow participation of aggregated demand response.

Aggregated demand response is accepted on all ancillary services and the newly commenced capacity mechanism [5]. As of today aggregated demand side response is not allowed to participate on wholesale electricity market through any mechanism.

Even though, aggregated demand side response is widely accepted on ancillary services, technical requirements could create meaningful limitations for participating on British ancillary service market.

To begin description of technical constraints, Firm Frequency Response ancillary service will be described. Despite the fact of rather low minimal bid and flexible availability scheme, FFR is out of reach for an aggregator of electric vehicles, as the mechanism does not accept turn down services [41].

Electric Vehicles aggregator will also not be able to join FFR Bridging, service designed for aggregators, as the minimal required load is too high: 10 MW [42]. Same limitation is will stop the aggregator from joining Fast Frequency Reserve, as the minimal bid is as high as 50 MW [43].

An electric vehicles aggregator will also not be allowed to participate in Enhanced Frequency Response (EFR) ancillary service, as the availability requirement could not be met. EFR requires statement of 95% availability throughout four years of a contract, which is unfeasible for EV aggregator [44].

Demand Turn-Up service was designed especially for demand side response aggregators, however the single aggregated unit must be bigger that 0,1 MW, a requirement that could not be met by aggregator of electric vehicles [45].

Consequently, the markets that remain a possible entry point in the UK are: STOR mechanism and capacity market .

The review of technical requirements set by National Grid (British TSO) is presented in Table 9 hereunder [5] [41] [43] [44] [45] [46].

Table 9 Technical requirements for market participation in United Kingdom

	FFR	FFR Bridging	Fast Reserve	STOR	EFR	Demand Turn-Up	Capacity Mechanism
Minimal Bid	1 MW	10 MW	50 MW	3 MW	1 MW	1MW aggregated from loads with minimal capacity of 0,1 MW	Assessed noticewise
Availability time	During tender period	During tender period	During tender period	2 h	95% of the tender period	30 min	Assessed noticewise
Maximum recovery time	–	–	–	20h	–	–	–
Notification Time	30s	30s	2 min	20 min	1s	10 min	4h
Tender period	Tender period is decided by the service provider	Tender period is decided by the service provider	Tender period is decided by the service provider	Week	4 years	Two weeks	–
Assessment	Unfeasible	Unfeasible	Unfeasible	Feasible	Unfeasible	Unfeasible	Feasible

Market Sizing

Table 10 hereunder presents the feasible entry markets size in volume, average availability payment, average utilization payment, and yearly revenues available on the market. Those are calculated basing on the market behaviour in 2017 published by NationalGrid [47].

The availability and utilisation payments of STOR mechanism are average payments for the flexible providers, which is the type of provider most suitable for an aggregator of electric vehicles, not requiring constant availability [46].

Majority of capacity market data is not available for capacity market as the service started running in early 2018 and market behaviour is yet to be set. Thus, the capacity market sizing is based on an estimation made by Mitchell Curtis from University of Reading [48].

As a reference point an, out of reach, service designed especially for demand side response participation is also presented in the table hereunder [5].

Table 10 Market Sizing of available British market entry points

	STOR	Capacity Mechanism
Market Size	3 444 MW	312 MW (for DSR)
Availability payments [£/MW/h]	3,125	8 400 £/MW annually
Utilization payments [£/MWh]	146,67	
Triggered per year	Several times per day	No data, service started running in 2018
Market Revenue	£ 90 000 000	£ 14 000 000

The data reflects that the current British market could be heading in the direction of developing new demand side response solutions, as new services dedicated to that technology are created (Demand Turn-Up). Furthermore, there is capacity dedicated to innovative, often demand side response solutions, on capacity market auctions [49].

Therefore, even though the size of demand side response market (Demand Turn-Up) is significantly lower than the size of STOR and Capacity Market, one should reflect that with DSR solutions also participating in STOR and capacity mechanism, UK is considering Demand Side Response as key factor in their modern energy strategies.

Market Saturation

Aggregated demand side response is allowed to participate on almost all British ancillary services and capacity market. However, only 7% of capacity contracted via STOR mechanism is demand side response. Furthermore, aggregated load reduction is accountable as 3% of STOR contracted capacity [47]. Furthermore, DSR is also disproportionately present on Capacity Market as February 2018 auction results show that 2,5% of contracted capacity is Demand Side Response [50].

United Kingdom is one of the leading regions regarding legislative and regulatory allowance of aggregated demand response [5], thus a significant number of aggregators participating in British markets is not surprising. There are currently, seventeen aggregators on STOR mechanism [47]. The share of aggregation among Capacity Market participants is less than 6%, that is twenty aggregators [51]. Furthermore, there are thirteen aggregators who simultaneously play on both markets: STOR and Capacity Market. Consequently, there is a total of twenty-four players on potential UK entry points.

The portfolio of an average British aggregator is a bit different than a portfolio of an average European aggregator. Opposite, to Belgium or France aggregators tend to target industrial plants as well as commercial businesses as their main clients. Out of twenty-four STOR and Capacity Market DSR aggregators, fifteen have commercial and industrial clients. Moreover, there are just six aggregators with strictly industrial clients.

Additionally, there are three aggregators focusing on commercial and residential demand side response: Origami Energy Limited, Upside Energy Limited and Open Energi. All of those aggregators have expressed an interest in balancing the grid with aggregated electric vehicles, which would prove a theoretical, lucrative, potential entry for EV aggregator, however would also mean a clear competition [52] [53] [54].

The potential of residential demand side response to be harvested by those aggregators already working towards that direction is significant. Potential of already adopting commercial demand side response is also meaningful.

That potential is presented on Figure 9 hereunder [18].

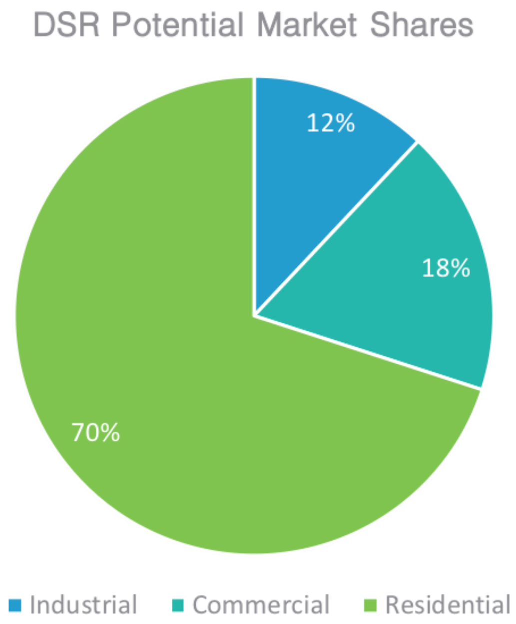


Figure 9 Structure of potential of Demand Side Response in the UK source(Demand response in Europe)

As United Kingdom has one of the most appropriately regulated energy markets for demand side response development, a significant competition is already considering using electric vehicles for grid balancing (Open Energi, Origami Energy Limited, Upside Energy Limited).

Although the total DSR potential is far from being tapped and available services demonstrate well market opportunities, one should consider the potential arising competition before trying to enter the energy market in United Kingdom.

3.5 Conclusion

Looking at the current state of regulatory framework concerning technical requirements of an aggregated fleet as well as single units, at the market sizes of potential entry points markets in one country and at the level of development of demand side response and aggregation, the author has decided to exclude following countries from further evaluation:

- Ireland, due to the lack of clear regulatory framework, as the country is currently preparing for adaptation of new market structure called I-SEM.
- Finland, as it has only one possible market to enter and the regulatory framework should be changing in the next few years once the Nordic countries finish pilot projects on demand side response, aggregation and flexibility.

The remaining markets in Belgium, France, Switzerland and United Kingdom, will be further analysed in the next chapters.

4. ANALYSIS OF ELECTRIC VEHICLES MARKETS

In this chapter, the possibility of development grid balancing with Smart Charging will be further analysed. Firstly, the sizes of electric vehicles markets will be analysed in each of the countries still remaining for further analysis. That is Belgium, France, Switzerland and United Kingdom. The analysis of electric vehicles markets will consist of:

- Assessment of current number of registered electric vehicles (focusing on battery electric vehicles and plug-in hybrids);
- Prediction of future number of registered electric vehicles, up until 2035;
- Analysis of distribution of charging points;

The current number of electric vehicles and the distribution of charging points was obtained by research of statistics in the given countries.

Whereas the prediction of future number of vehicles will be obtained by the author, through the method of linear or nonlinear regression of the data of new registration of vehicles over the last decade. Basing on the growth of number of new registration of electric vehicles each year during the last decade, the trend of growth could be estimated. Later on, that trend of growth will be used to predict the number of vehicles in a certain country over the course of next two decades.

The prediction will be either done basing on linear or nonlinear regression. At this point an author analyses the current trend of overall EV market development along with the local country level trend and decides which regression should be used in each case.

As for the distribution of charging points, only certain charging locations could be considered as valuable by the aggregator. That is because aggregation of electric vehicles to balance the grid, could only be made during a certain process of charging.

The requirements of that process are as follows;

- The charging process should be meaningfully long, so that the aggregator could benefit from charging by changing the speed of charge;
- The owner of electric vehicle should be able to receive remuneration for her/his contribution to the balancing process;
- The charger should have a hardware allowing aggregator to control the speed of charge.

Basing on the requirements for the process of charge, key charging points of interest were identified. First and foremost, the charging should not be done at a fast charging point, as the vehicle would not be available for grid balancing for a meaningful amount of time. Secondly, the charging point should be most likely owned privately, so that the aggregator could easily install the hardware needed to control the charger [7]. Thirdly, the charging location should ensure limited and known users, so that the aggregator could use their charging process to balance the grid.

The only charging points that meet all those requirements, are standard and mid-accelerated office and household charging points, therefore in the distribution of charging points the author will try to answer whether current allocation of charging points and charging patterns for each country, could be enough for the aggregator to balance the grid in said country.

The results of electric vehicle market analysis in the scope of possibility of grid balancing with aggregated EVs is presented hereunder.

4.1 Belgium

4.1.1 EV market nowadays

Belgian electric vehicles market has started to grow rapidly in 2013. However, the market is still relatively small, as electric vehicles represented only 0,5% of all passenger vehicles in 2017. As of the end of 2017 there was almost 32 000 electric vehicles registered in Belgium, this number reflects registered plug in hybrid electric passenger vehicles and battery electric passenger vehicles [55].

The consistent growth of EV market in Belgium is presented on the figure hereunder, going along with the current worldwide showing that drivers in developed countries tend to choose electric vehicles more often, the polynomial trend line, was chosen as the most suitable. The trendline is presented as well on Figure 10 hereunder.

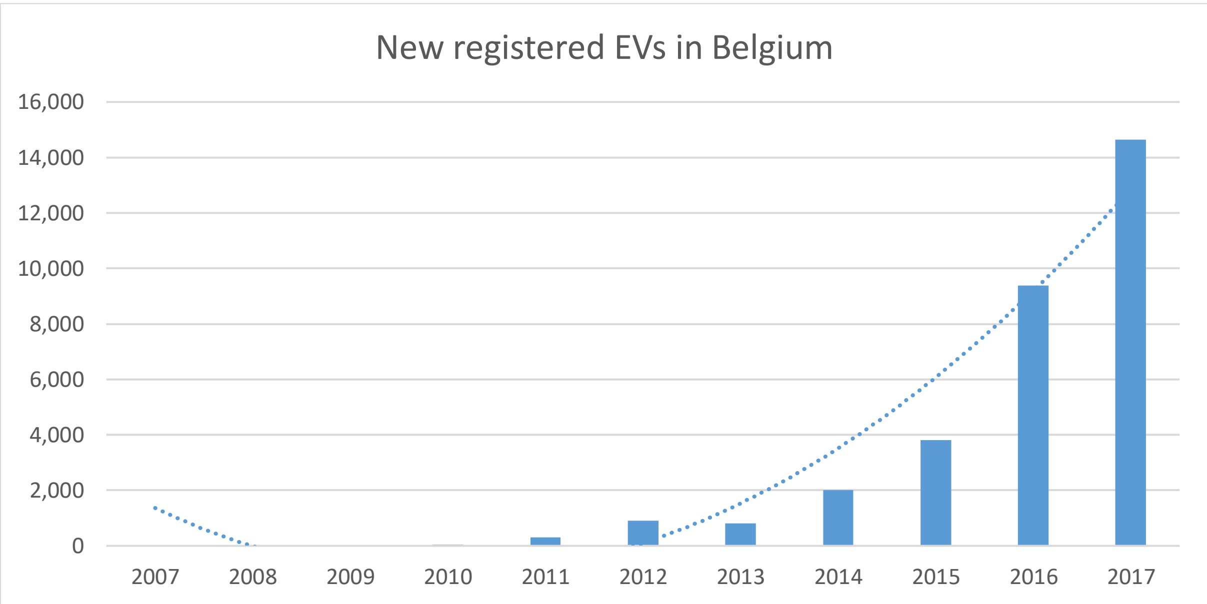


Figure 10 New registration of EVs in Belgium

4.1.2 Prediction of the future of EV market

The prediction of overall number of EVs present on Belgian roads is presented on Figure 11 hereunder. Prediction was created basing on the trendline found before, as well as the assumption that the average lifetime of an EV to 20 years [56].

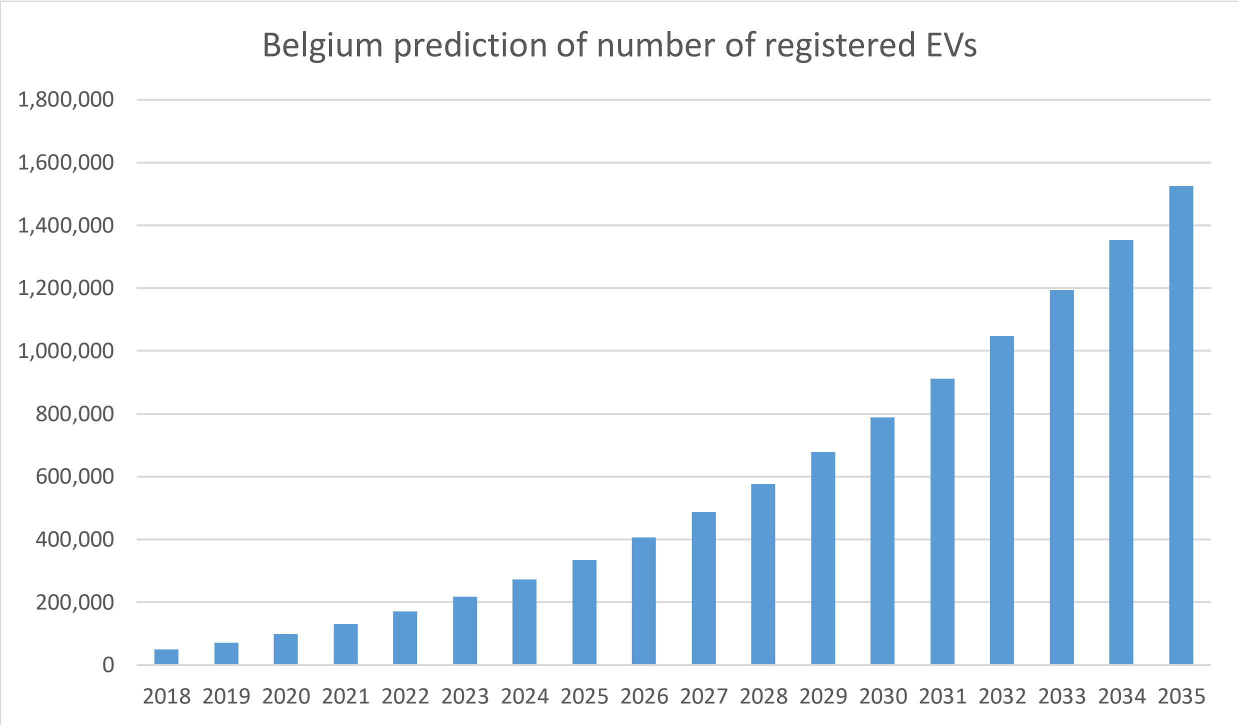


Figure 11 Prediction of number of Electric Vehicles in Belgium

The analysis shows that by 2035 almost one and a half million of passenger electric vehicles could be present on Belgian roads, which as around 25% of nowadays passenger vehicle fleet could be considered a reasonable result [55].

4.1.3 Distribution of charging points

The information about the number of home and office chargers was not available to the author, however basing on the overall European data about charging station distribution an approximation could be made.

Based on a study "*Projections for electric vehicle load profiles in Europe based on travel survey data"* conducted by G. Pasaoglu, D. Fiorello, L, Zani, A. Martino, A. Zurbayeva and C. Thiel, as for now 60% of charging station are publicly accessible, whereas 21% is located at the offices and 19% is household charging [57].

If this European approximation is used, knowing that there are around 1 800 publicly accessible charging points in Belgium, there should be around 650 charging points located in offices and around 600 those located at private households [55].

Furthermore, the charging points that are located at the offices and households are either standard or mid-accelerated and privately owned.

Therefore, in Belgium around 1 250 charging points should be available for an aggregator to control.

4.2 France

4.2.1 EV market nowadays

Electric Vehicles in France have been becoming more and more popular among the buyers each year, and the market is growing rapidly. Currently more than 2% of all sold passenger vehicles are electric, with more than 100 000 of electric vehicles already present on French roads, counting both PHEVs and BEVs [58]

The unfailing growth of EV market in France is presented on Figure 12 hereunder. Electric vehicles are of key to mobility strategy of France, EVs are also heavily subsidised in France, therefore a rapid growth of the fleet is to be expected [59]. Thus, again a nonlinear trend line was debated as the most suitable growth for predicting the number of EVs in France over the next two decades. The trendline, along the with the statistics on new registrations of electric vehicles each year are presented on a following graph.

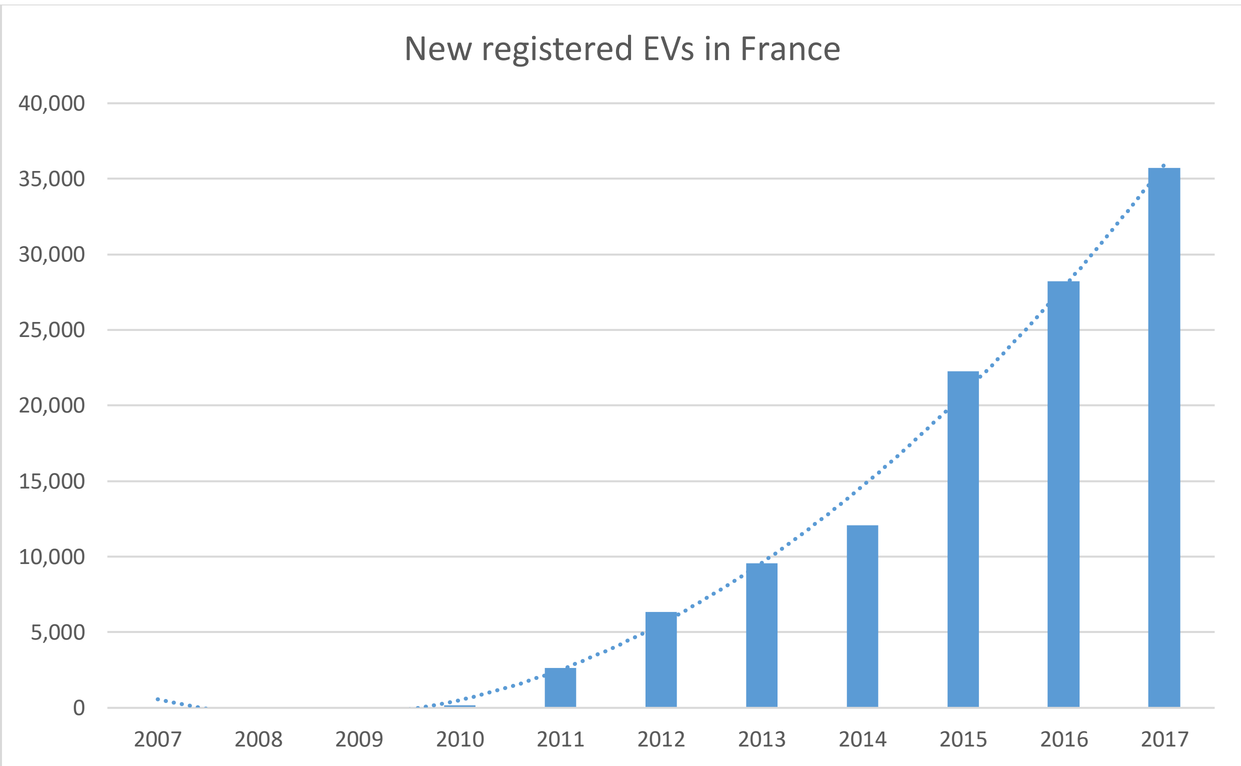


Figure 12 New registration of EVs in France

4.2.2 Prediction of the future of EV market

The prediction of overall number of EVs present on French roads is presented on Figure 13 hereunder. Prediction was created basing on the trendline found before, as well as the assumption that the average lifetime of an EV to 20 years [56].

Furthermore, the prediction was validated by Bloomberg New Energy Finance forecasts that there would be 28 times more EVs in the road in 2030 as there were in 2016 [59].

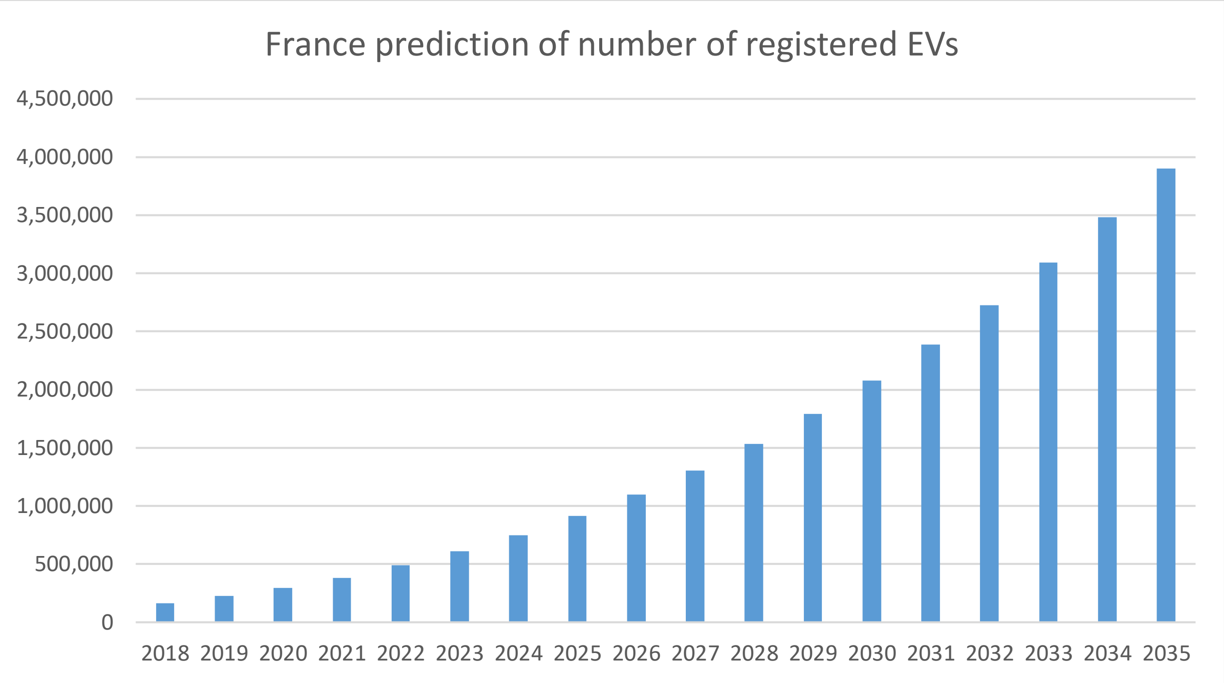


Figure 13 Prediction of number of Electric Vehicles in France

The analysis shows that by 2035 almost four million of passenger electric vehicles could be found on French roads, which as around 13% of nowadays passenger vehicle fleet could be considered a very safe result. Furthermore, the result shows over 2 000 000 EVs registered in 2030 which is roughly 28 times what the number was in 2016. Thus, the results of the analysis could be treated as plausible.

4.2.3 Distribution of charging points

The information about the number of home and office chargers was not available to the author, however basing on the overall European data about charging station distribution a rough approximation could be made.

Similarly, to the analysis for Belgian market, the same study is used to estimate the number of charging points in France.

If this European approximation is used, knowing that there are around 16 265 publicly accessible French charging points, there should be around 5 700 charging points located in offices and around 5 200 of those located in private households [58].

Furthermore, the charging points that are located at the offices and households are either standard or mid-accelerated and privately owned. Therefore, around 11 000 charging points should be available for an aggregator to control in France.

4.3 Switzerland

4.3.1 EV market nowadays

Swiss are more and more likely to buy an EV with every single year. The sales have been growing, and it is highly expected that this trend will continue during the next decades. Currently only 0,6% of all passenger vehicles are electric, with around 25 000 of electric vehicles already present on the roads, counting both PHEVs and BEVs [60].

The unfailing growth of EV market in Switzerland is presented on Figure 14 hereunder. Electric vehicles markets is said to grow rapidly during the course of next decades, as the vehicles gain more social trust and become more reliable [61]. Thus, again a nonlinear trend line was debated as the most suitable growth for predicting the number of EVs in Switzerland over the next two decades. The trendline, along the with the statistics on new registrations of electric vehicles each year are presented on a following graph.

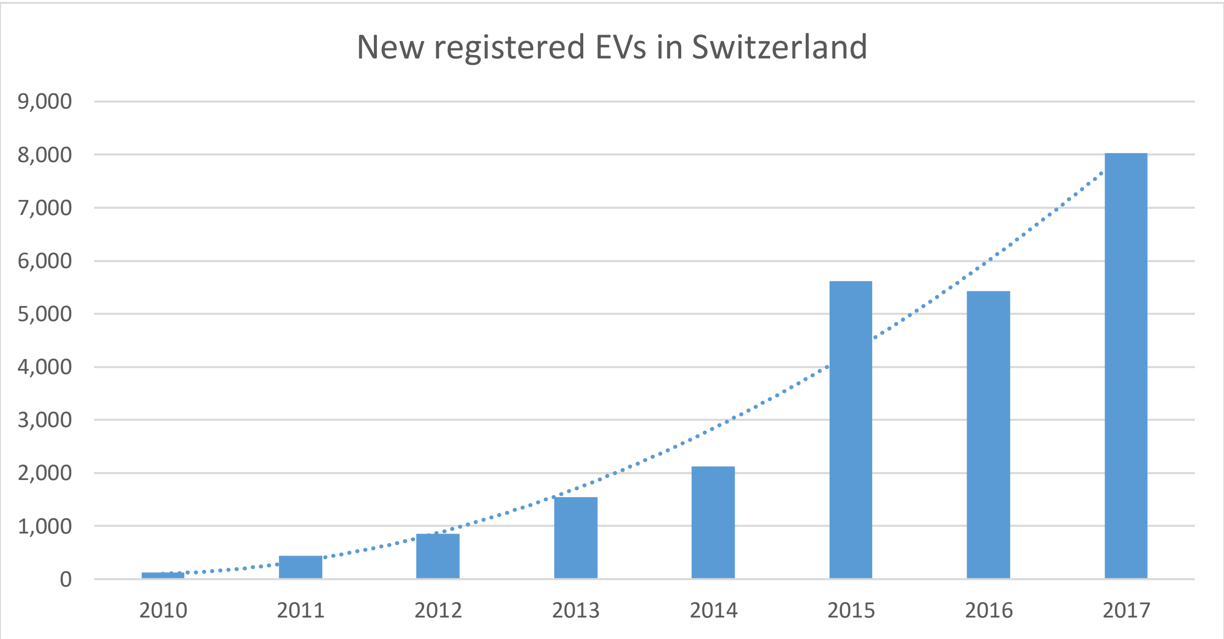


Figure 14 New registration of EVs in Switzerland

4.3.2 Prediction of the future of EV market

The prediction of overall number of EVs riding on roads in Switzerland during the next decades is presented hereunder on Figure 15. Prediction was created basing on the trendline found before, as well as the assumption that the average lifetime of an EV is 20 years [56].

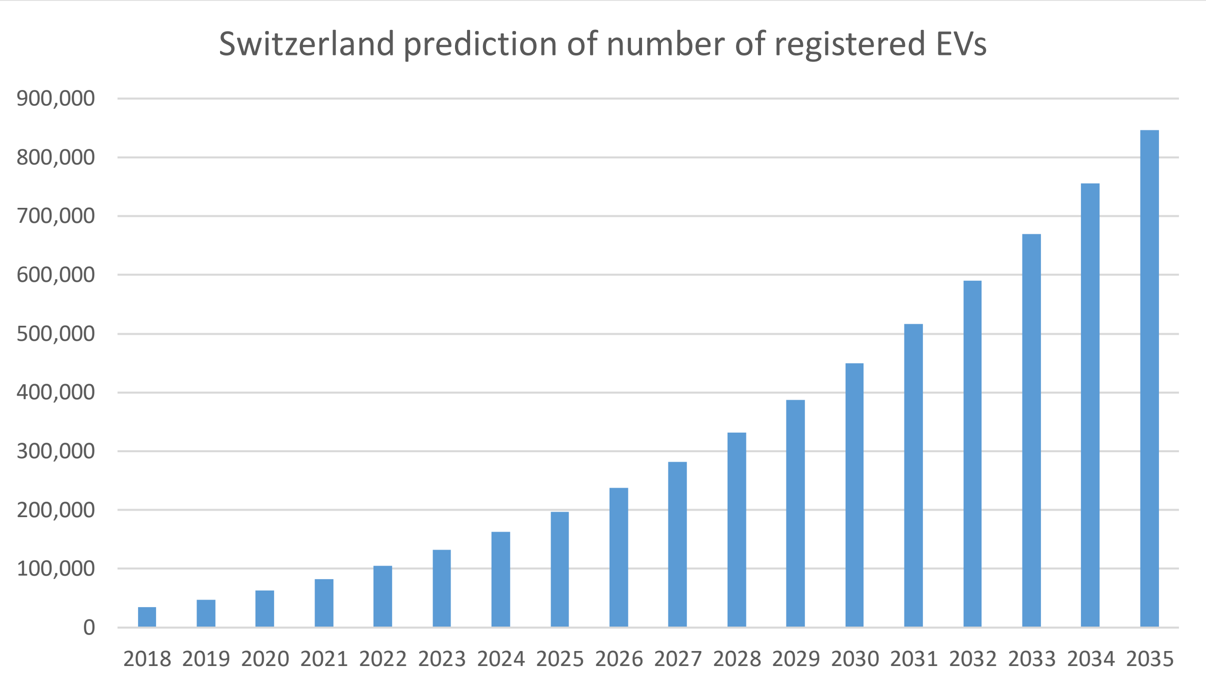


Figure 15 Prediction of number of Electric Vehicles in Switzerland

The analysis shows that by 2035 almost a million of passenger electric vehicles could be present on Swiss roads, which as around 20% of nowadays passenger vehicle fleet could be considered a very safe result. The expected number of vehicles in 2035 therefore, could be much higher than what the author is safely predicting here [59].

4.3.3 Distribution of charging points

The information about the number of home and office chargers was not available to the author, however basing on the overall European data about charging station distribution a rough approximation could be made.

If, as previously, European Commission's approximation is used, knowing that there are around 4 000 publicly accessible Swiss charging points, there should be around 1 400 charging points located in offices and around 1 300 of those located in private households [60].

Furthermore, the charging points that are located at the offices and households are either standard or mid-accelerated and privately owned. Therefore, around 2 700 charging points should be available for an aggregator to control in Switzerland.

4.4 United Kingdom

4.4.1 EV market nowadays

British electric vehicles market has started to grow rapidly in 2014. However, the market is still relatively small, as electric vehicles represented only 0,5% of all passenger vehicles in 2017. As of the end of 2017 there were 135 000 electric vehicles registered in United Kingdom, that number reflects registered PHEVs and BEVs [62].

Electric vehicles markets is said to grow rapidly during the course of next decades, as the vehicles gain more social trust and become more reliable. Moreover, this growth is expected to sustain with the incentive system proposed by the British government and strategy aiming towards electric mobility [63]. Thus, again, a nonlinear trend line was debated as the most suitable growth for predicting the number of EVs in the UK over the next two decades. The trendline, along the with the statistics on new registrations of electric vehicles each year are presented on Figure 16.

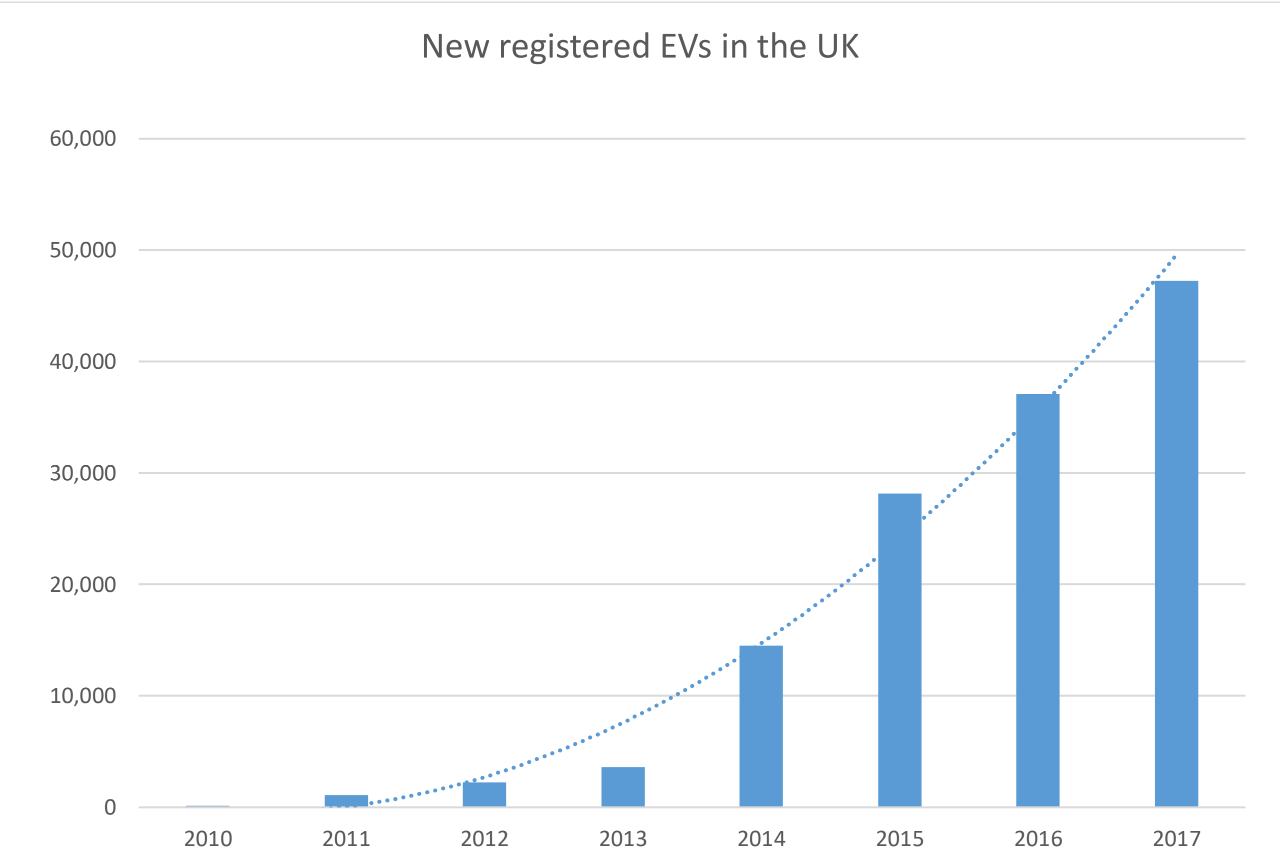


Figure 16 New registration of EVs in the UK

4.4.2 Prediction of the future of EV market

The prediction of overall number of EVs present on roads in the UK during the next years is presented hereunder on Figure 17. Prediction was created basing on the trendline found before, as well as the assumption that the average lifetime of an EV is again 20 years.

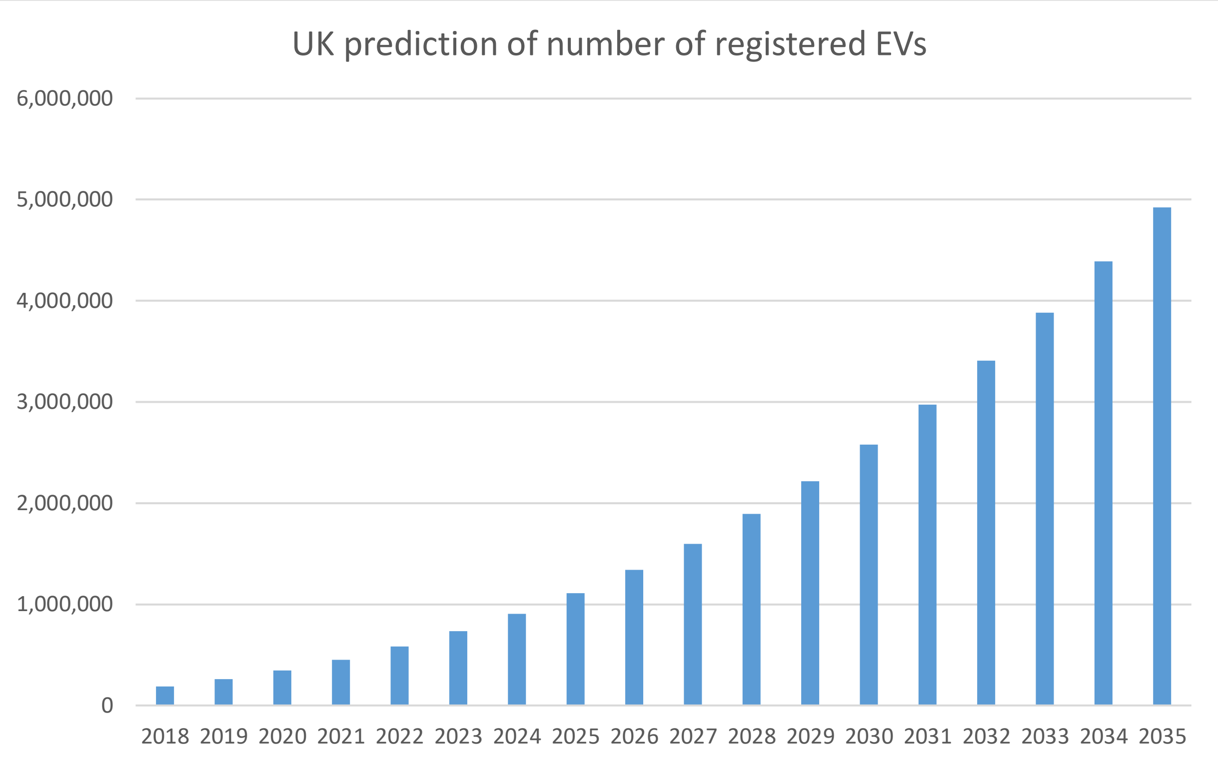


Figure 17 Prediction of number of Electric Vehicles in the UK

The analysis shows that by 2035 almost a five million of passenger electric vehicles could be present on roads in the UK, which as around 18% of nowadays passenger vehicle fleet could be considered a very safe result. The expected number of vehicles in 2035 therefore, could be much higher than what the author is safely predicting here. However, this prediction is created to estimate the potential business model for an aggregator, therefore a safe estimation, without the risk of overestimation, is preferred. Additionally, the prediction is in line with BNEF estimation of EV fleet being 28 times as much in 2030 as it was in 2016.

4.4.3 Distribution of charging points

The information about the number of home and office chargers was not available to the author, however basing on the overall European data about charging station distribution a rough approximation could be made.

Based on a study "*Projections for electric vehicle load profiles in Europe based on travel survey data"* conducted by G. Pasaoglu, D. Fiorello, L, Zani, A. Martino, A. Zurbayeva and C. Thiel, as for now 60% of charging station are publicly accessible, whereas 21% is located at the offices and 19% is household charging. [57]

If this European approximation is used, knowing that there are around 16 500 publicly accessible British charging points, there should be around 5 800 charging points located in offices and around 5 250 of those located in private households [62].

Furthermore, the charging points that are located at the offices and households are either standard or mid-accelerated and privately owned. Therefore, around 11 000 charging points should be available for an aggregator to control in the UK.

4.5 Conclusions

Looking at the overall trend, EVs tend to be more present on our roads. This trend is said to last during the next decades, eventually margining the usage of conventional internal combustion engines. [59] Same tendency is also illustrated in the predictions presented in this paper.

Combining the regulatory framework and technical requirements, presented in the previous chapter, with the findings of electric vehicles market in selected four European countries, the right pathway of market entry for an EV aggregator could be deducted.

It has been concluded that the amount of suitable charging points and the number of electric vehicles is already sufficient to support aggregators business model, to balance the grid according to the technical requirements, in the UK and in France.

Furthermore, as the minimal bid is not extensively large in Belgium, and the number of EVs will grow rapidly with the current governmental incentives, Belgian market could also be an entry point for an aggregator.

However, with a large minimal bid required by Swissgrid (5 MW) and the relatively low current number of electric vehicles and suitable chargers the aggregator could be limited to enter Swiss market.

Nevertheless, all of the presented markets, that is, Belgium, France, UK and Switzerland will be analysed further in terms of rough estimation of profitability of the market.

5. Rough estimation of market profitability

The purpose of this chapter is to further investigate the possibility of developing a lucrative business model on grid balancing with Electric Vehicles. Thus, a rough estimate of a profitability of each market participation will be presented in this chapter.

The profitability analysis will be made basing on the market data from the previous year (2017). For each service the average availability and utilisation payments will be found and used. Thereafter, basing on the requirements of the market and the minimal or desired bid a rough estimation of profitability per 1 MW per year will be done.

5.1 Belgium

The ancillary services that are theoretically open for an aggregator to balance the gird with electric vehicles are R1 Load Up and Strategic Reserve for Demand Response (SDR). The profitability of those markets will be established in this subchapter.

First and foremost, data about Strategic reserve is not available to obtain for a third party, therefore only profitability of R1 Load Up will be estimated, basing on the historical market data for 2017 available on the website of Belgian TSO: Elia. [10]

The profitability will be calculated basing on the number of days the service was activated and utilised in 2017, that is 70 minutes per year [5] [64].

Furthermore, since the time constraints for the availability period are most troubling for the aggregator, the shortest possible availability window is used for the estimation, that is 4 hours, the tender period that Elia is interested in pursuing.

Moreover, due to the fact that EV market is still emerging the minimal bid required will be considered for the profitability estimation.

Average utilisation and availability payment will be calculated from the market data of the previous year.

The profitability is calculated basing on the number of days the aggregator is requested to be available for a tender period multiplied by the average availability payment. Since there is no utilisation payment the utilisation factor is not included in the calculations.

The data used for profitability calculation along with the result is presented in Table 11 hereunder.

Table 11 Profitability estimation for Belgium

	Minimal Bid	Tender period	Number of days available	Time period for utilisation	Average availability payment [€/MW/h]	Average utilization payment [€/MWh]	Revenues per min bid per year
FCR (R1 Load Up)	1 MW	4 h	365	70 min	7,87	0	11 490

The total yearly profitability for 1 MW available each day for 4 hours was estimated for 11 490 €.

5.2 France

The aggregator can balance the grid with electric vehicles in two main markets: FCR primary reserve and on the wholesale market, through NEBEF mechanism. The profitability of those markets will be analysed in this sub-chapter. Again the analysis will be made basing on the historical market data from 2017.

5.2.1 FCR

First, the profitability analysis will be made basing on the assumption that the tender period will go down to 4 hours, which RTE expressed interest in. The analysis will also be made for a minimal requested bid, which is 1 MW.

The results are obtained basing on the analysis of the historical market data from 2017 made available to the author by French TSO [23].

The data provided from 2017 is

- The average availability payment
- The average utilisation payment
- Number of days the aggregator could be requested to make their capacity available
- Number of days the aggregator could be requested to make their capacity activated

The number of days that aggregator could be requested to make their capacity available is the number of days that RTE requests available capacity higher than minimal bid for a period longer than considered tender period.

The number of days that aggregator could be requested to make their capacity activated is the number of days that RTE activates capacity higher than minimal bid.

For simplification of the calculation there is an assumption that the aggregator will win all auctions for utilisation of 4 hours. The assumption will allow to estimate the highest possible revenue available on the market.

After careful analysis of the data for 2017, the author could perform the profitability analysis presented briefly in Table 12.

Table 12 Profitability estimation for France FCR

	Minimal Bid	Tender period	Number of days available	Number of days activated	Average availability payment [€/MW/h]	Average utilization payment [€/MWh]	Revenues per year
FCR	1 MW	4 hours	365	335	7,42	44,29	70 182€

The results of the analysis show that over 70 000 € is available for the aggregator yearly on the French FCR market. However the aggregator is not expected to make such profits, as the previously assumed 100% activation is unlikely.

5.2.2 NEBEF

The results are obtained basing on the analysis of the historical market data from 2017 made available to the author by French TSO [22].

The data provided from 2017 is:

- Payment for each MW of capacity deletion
- The market data for requested deletions

The author assumed the basic scheme of payment, which provides the aggregator with the same payment each time the deletion of capacity is made: that is 43,58 euro/MWh. In other tariffs the payment varies between off peak and peak demand time slots and seasons. However, as this profitability evaluation is supposed to be a rough estimation allowing to assess the markets the basic tariff was chosen for the sake of simplicity of calculations.

The number of days that aggregator could be requested go down with their capacity will be estimated basing on the historical market data from 2017.

The author chose to make a profitability estimation similar to this of FCR. Thus the bid used for this estimation is not the minimal NEBEF bid (0,1 MW), but 1 MW, and the period in which deletion could occur is limited to 4 hours a day.

After careful analysis of the data for 2017, the author could perform the profitability analysis presented hereunder in Table 13.

Table 13 Profitability estimation for France NEBEF mechanism

	Assumed Bid	Assumed availability period	Number of days activated	Payment [€/MWh]	Revenues per year
NEBEF	1 MW	4 h	172	43,58	29 983€

The results of the analysis show that almost 30 000 € is available for the aggregator yearly through the French Nebef mechanism. However the aggregator is expected to possibly make more as only the periods of 4 hours were taken into account, to easily compare with FCR. Furthermore, the aggregator could choose a different tariff of deletion, which could also increase the profitability.

5.3 Switzerland

There is only way the EV aggregator could access the market in Switzerland, that is through the tertiary reserve daily ancillary service (RR positive and negative). Thus, this market will be analysed in terms of plausible profitability.

The profitability estimation is based on the historical market data from 2017, available to obtain through SwissGrid [35].

The profitability will be calculated basing on the number of days the service was activated and utilised in 2017.

Furthermore, since the time constraints for the availability period are most troubling for the aggregator, the shortest possible availability window is used for the estimation, that is 4 hours which is one timeslot per day.

Moreover, due to the fact that EV market is still emerging the minimal bid required will be considered for the profitability estimation, which is still considered high: 5 MW.

Average utilisation and availability payment will be calculated from the market data of the previous year.

Again, the 100% activation is assumed to estimate the highest possible earnings from the market.

The data used for profitability calculation along with the result is presented in Table 14 hereunder.

Table 14 Profitability estimation for Switzerland

	Minimal Bid	Tender period	Number of days available	Number of days with activation	Average availability payment [CHF/MW/h]	Average utilization payment [CHF/MW/h]	Revenues per year in CHF
RR + Daily	5 MW	4 h	365	48	2,12	95,16	109 390 CHF
RR - Daily	5 MW	4 h	365	58	1,84	37,64	78 288 CHF

The total yearly profitability of Swiss tertiary reserve ancillary service is 187 678 CHF for 5 MW per year. That is 37 536 CHF per 1 MW per year.

5.4 United Kingdom

The ancillary services that are theoretically open for an aggregator to balance the gird with electric vehicles STOR, which is directed are demand side response and Capacity Market, which has a defined capacity available for DSR. The profitability of those markets will be established in this subchapter.

5.4.1 STOR

The profitability of STOR will be estimated basing on the historical market data from 2017, available through National Grid [47].

The profitability will be calculated basing on the number of days the service was activated and utilised in 2017.

Furthermore, since the EV market is still developing and this is a study of an entry point the minimal technical requirements will be used to estimate the profitability. Those are 3 MW of minimal bid available for at least 2 hours.

Average utilisation and availability payment will be calculated from the market data of the previous year.

The author will assume that the aggregator would win 100% of all possible auctions. That assumption will lead to probable overestimation of profitability, but will allow to estimate the upper threshold of profitability of this market.

The data used for profitability calculation along with the result is presented in Table 15 hereunder.

Table 15 Profitability estimation for the UK STOR

	Minimal Bid	Tender period	Number of days the service is requested	Number of days the service is activated	Average availability payment [£/MW/h]	Average utilization payment [£/MWh]	Revenues per year
STOR	3 MW	2 h	243	243	1,76	100	148 366£

The total yearly profitability for 3 MW was estimated at 146 366 £, which equals to 49 455 £ of revenues for each MW available.

5.4.2 Capacity Market

The capacity market profitability estimation varies from other ancillary services, as the unit is paid per kW, for making itself available throughout the whole year. This year the market cleared the price at 8,4 £/kW [50]. Therefore, looking at the minimal technical requirement of 2 MW, the aggregator would make 16 800 £ yearly.

5.4 Conclusion

Figure 18 hereunder, represents the profitability of each analysed markets in euros. The currency exchange was made basing on today's day value (25.06.2018).

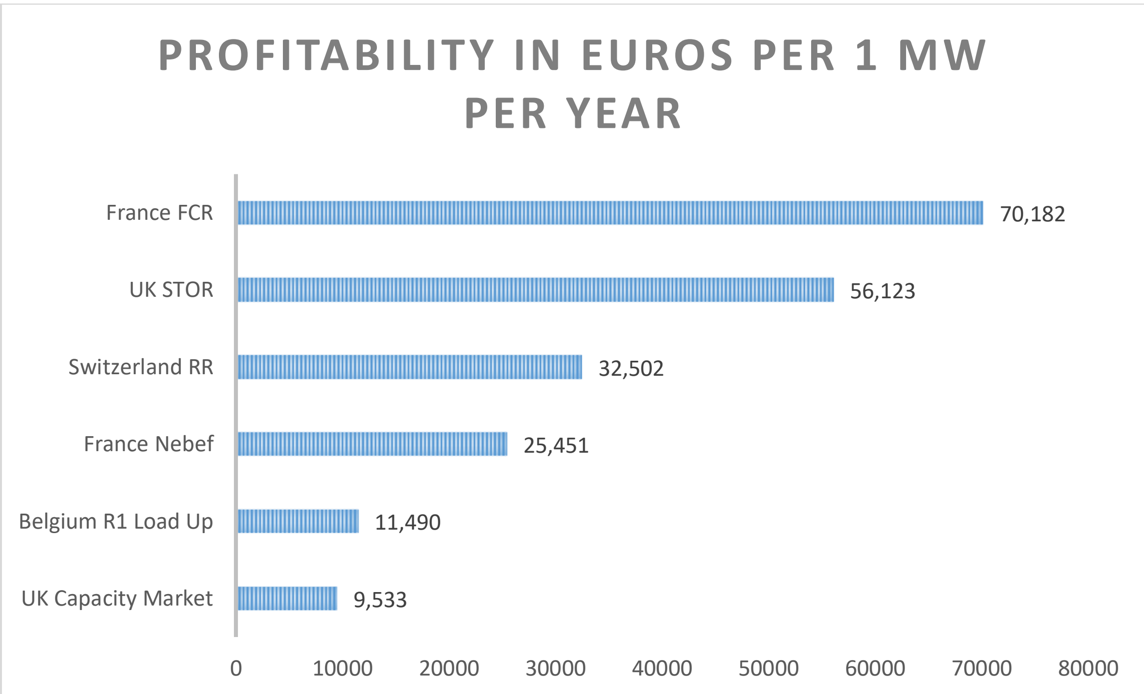


Figure 18 Comparison of profitability of all markets

Looking at the graph, one can easily see that the most profitable market is FCR in France, however entering in this market could be troublesome as the fleet of cars should be extensively big, due to the requirement of symmetrical deliverance.

Another profitable option is UK STOR, however the competition in the UK is already emerging, as previously mentioned.

The next most profitable market is Swiss RR, however the extensive bid of 5 MW could be a meaningful limitation for an EV aggregator, due to the still low number of electric vehicles in Switzerland.

Furthermore, for all those markets the profitability is could easily be overestimated, as it assumes the 100% of auction wins, which could be highly implausible, even with the minimal bid.

On the other hand, the profitability of NEBEF (the fourth most profitable market) could be underestimated, as only the 4 hour long cancellations were taken into account. Additionally, Nebef is an erasure of capacity mechanism designed especially for DSR emerging business cases.

Due to much lower possible revenues the capacity market could be considered as an entry market in case of development the business case in the UK, as well through STOR.

Overall the Belgian market would bring the lowest revenues to the aggregator, and with still low number of EVs and an unsure situation with the tender period is not considered as a good entry market.

6. Methodology

The aim of this chapter is to provide the reader with the methodology taken in order to obtain results of economic and environmental analysis of grid balancing with smart charging of electric vehicles.

6.1 Market choice

The author has decided to focus the optimisation model on NEBEF mechanism, due to numerous reasons shortly presented hereunder.

Firstly, Swiss market was eliminated because of extensive technical requirements, minimal capacity of 5 MW sustained for at least 4 hours would require an out of reach amount of cars for an entry market in Switzerland, where the EV market is has not sufficiently developed yet.

Secondly, Belgium was eliminated as a market with low estimated profitability with still inadequately developed EV market.

Thirdly, the UK Capacity Market could not be studied further as it only emerged at the beginning of this year and there is no historical market data available yet.

Fourthly, it was impossible to study detailed market behaviour of UK STOR ancillary service, due to lack of available data. National grid publishes only informational yearly report instead of detailed everyday data on requested and accepted capacity along with the prices, which is needed to perform the optimisation.

Fifthly, and lastly, the only remaining markets were French: FCR and NEBEF mechanism. Out of the two the author decided to focus on NEBEF, as FCR's requirement to deliver symmetrical output could be troublesome for an aggregator.

NEBEF erasure mechanism is also favourable for an aggregator as there are no penalties issued for over or under deliverance of the previously declared capacity erasure. [20]

Additionally, NEBEF is one of few European markets allowing DSR actions, in form of capacity reductions, on wholesale market, which is strongly believed to be the future of congestion management of electrical grid [5].

Therefore, looking at the future possibilities of those erasures programmes, the author decided to focus the market behaviour model on innovative NEBEF mechanism.

6.2 Market Data

Data needed to create this analysis was made public by RTE [22] [65]. Data needed by the model is the required erasure capacity in a given time and date. RTE gives out data of the requested and accepted erasure capacity each half hour.

The data used in the model is a historical requested erasures information from 2017. RTE also proved information about the pricing schemes of the NEBEF mechanism. There are three pricing schemes offered by the erasure mechanism.

Pricing scheme one

The market participant is payed the same price for each provided erasure, regardless of time of service. In 2017 the price was 43,58 € per erased MWh [65].

Pricing scheme two

The market participant is payed a different amount in regard to the time of the offered erasure. The participant will be paid more during the peak hours, that are set by RTE as everyday between 7 am and 11 pm. The participant will be payed less for the erasure offered during base hours, that is between 11 pm and 7 am. The prices per each erased MWh in 2017 where 34,42 € during the base hours and 49,90 € during the peak hours [65].

Pricing scheme three

The market participant gets a different payment per MWh erased depending on the time of the day and the type of the day, as well as the season. The erasure is valued at peak prices between 8 am and 8 pm on each working day, and as base between 8 pm and 8 am on working days and during weekends and public holidays. Moreover the prices vary dependant on the quarter of the year. The prices per each erased MWh are presented in Table 16 hereunder [65].

Table 16 Prices of NEBEF mechanism pricing scheme 3

	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
	Peak	Base	Peak	Base	Peak	Base	Peak	Base
Price [€/MWh]	44,20	73,97	29,12	41,56	28,63	41,95	37,64	62,09

The analysis is be based on a pricing scheme three, as this is the one addressed to withdrawal sites read remotely, which is suitable for the electric vehicle aggregator, controlling smart chargers with smart meters installed within.

Another Market Data parameter used is carbon intensity of French electricity generation. The average of 80 grams of CO_2 per kWh (in 2017) was obtained from Open Data published by RTE. [66]

6.3 Driving and charging patterns

As the model studies possibilities of grid balancing with electric vehicle smart charging, the model must include the charging and driving patterns of EV owners. The patterns used to deploy the model are presented in this subchapter.

The driving patterns used for the model were studied and presented in the paper written by C.Cochero *“European electric vehicle fleet: driving and charging behaviours”.* The study presents that the average plug in time is longer than the actual charging time of electric vehicle. That is what creates the opportunity for an aggregator to lower the demand and thus participate in the erasure programme.

For the purpose of this analysis two driving and charging patterns are being considered. Those are driving and charging patterns of individuals charging at their own home and individuals charging at the office. The purpose of this is to find out whether the aggregator should target company fleets of EVs or private owners of EVs.

The important factors that need to be taken into account while creating the driving and charging model are:

- The frequency of charging occurrence.
- The time the driver plugs in to the charger.
- The time the driver plugs out of the charger.
- The energy that the driver requires to charge.
- The power of the charger.
- The minimal current of charging.

The first four factors will be taken out of the analysis made by C.Cochero. The remaining two would be a factor of scenario analysis that could show the aggregator what types of chargers to target (the factor of charging power) as well as whether the continuous charging, would be a meaningful limitation in comparison with on and off charging (the factor of minimal current).

The driving and charging patterns used for the purpose of analysis are presented in the subchapter hereunder.

6.3.1 Charging at the office

Office workers tend to charge their EV every working day of the week. The tendency shows that the car is charged until full, implied by 100% State Of Charge at the end of charging process [67].

The average charge energy required by drivers charging in their offices is taken from the study and is equal to 6,85 kWh. Additionally, typically the car is connected to the charger for 5 hours on average [67].

The time the driver plugs in to the charger was determined in the paper mentioned beforehand and is presented on Figure 19 hereunder [67].

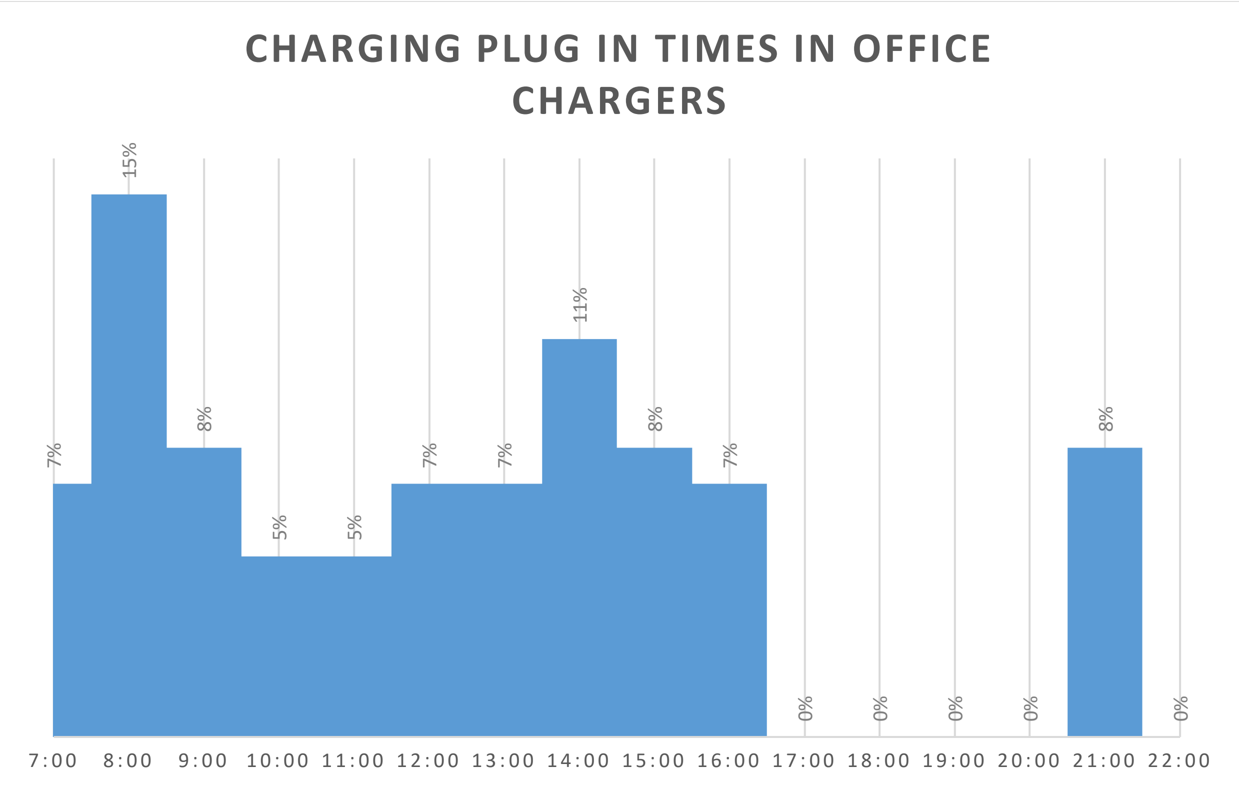


Figure 19 Charging plug in time for office chargers

The reader can deduct from the graph that 7% of the cars start charging between 7 and 8 o'clock in the morning. However, even though it is the only information provided, it is not enough information to create successful pattern allowing to estimate market potential. Thus, the author decided to allocate the starting time of charge randomly in between those specified hours in a time range of five minutes.

A careful eye will notice that only 88% of charging events is located on the graph. The remaining 12% is allocated randomly, as those where charging events that did not fit the pattern. Those allocated randomly 12% represent the spontaneous charging behaviour.

6.3.2 Charging at home

Private owners of EVs charging at home tend to connect their vehicle to the charger daily, and keep it connected until the car is fully charged [67].

The average charge (energy required) by drivers charging in at home is taken from the study and is equal to 8,82 kWh. The car is connected to the charger for 5 hours on average [67].

Again, the time the driver plugs in to the charger was determined in the paper mentioned beforehand and is presented on Figure 20 hereunder [67].

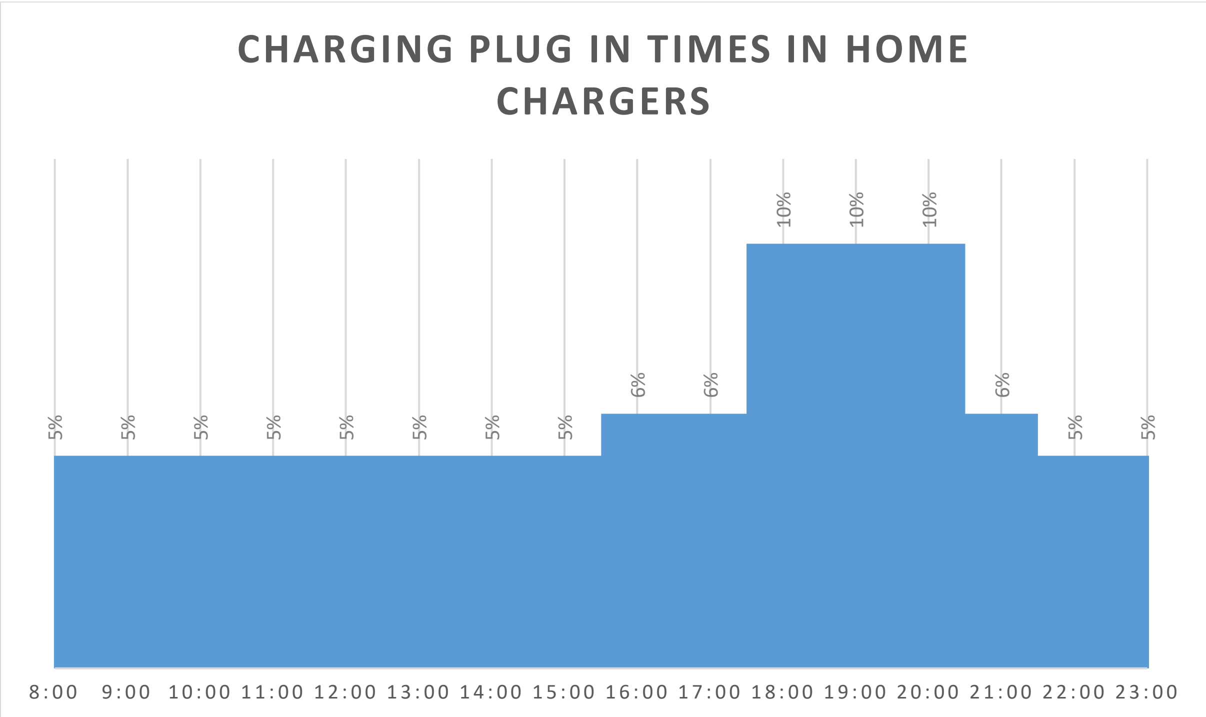


Figure 20 Charging plug in time for home chargers

The distribution of arrival of drivers is determined only between two hours, as in the previous case, therefore the allocation of the start of charging is randomly assigned by the author within the model in the intervals of 5 minutes, to make sure that the results are closer to reality.

All of the major tendencies of charging at home are presented on Figure 20, however not all of the charging events are there. The remaining 8% of charging is randomly allocated. This underlines the spontaneity of human behaviour as well as covers the minor propensities of night charging.

6.4 Optimisation methodology

The author has created the model allowing to optimise the charging process in order to obtain favourable remuneration for the erasure of capacity. The optimisation is done daily for a given fleet of electric vehicles. The user can input a number of vehicles charging at offices and at homes, and the system will follow the patter provided beforehand. Once the optimisation is made for a certain day the model will proceed to the next day, and end in optimisation of the whole year.

The model was built with the use of Python Programming Environment. The data was prepared beforehand with the use of Pandas and Numpy libraries to have the right format, structure, units and merge all required variables for the optimization into one dataset.

Having the data frame already prepared, the optimization problem was stated. The model was built with the use of SciPy library, with the optimization technique Sequential Least Squares Programming (SLSQP). The SLSQP aims at minimizing a function of several variables with any combination of bounds, equality and inequality constraints. The author of this thesis decided to apply this particular methodology as it enables to solve constrained optimization problem. The method wraps the SLSQP Optimization technique originally implemented by Dieter Kraft [68].

The optimisation follows the given objective function, which aims to maximize the revenues for the aggregator. The function is as follows.

$$MAX\left(\sum_{t}(P_{MAX} - P) \cdot \Delta t \cdot price(t)\right)$$

Where,

P_{MAX} is the maximal charging power at which the electric vehicle would be charging if not for the aggregator.

P is the optimal charging power at a given moment in time maximising the profits for the aggregator.

Δt is the timestamp, set to 5 minutes.

$price(t)$ is the price given for the erasure of demand at a given time.

The constraints used for the optimisation are as follows:

- $\sum_i P \cdot t_i = E_{req}$
- $P \geq P_{min}$
- $P \leq P_{max}$
- $P_{tot} \geq 100\ kW$

- Constant Power Charging Constraint: if $P_{tot}(t) \geq 100\ kW$, P_{tot} has to be constant within the timeframe equal to 5 timestamps (t, t+1, … t+4) of power erasure offered to the market.

E_{req} is the energy the driver will require to charge, set to 6,85 kWh for users charging at the office and to 8,82 kWh to those charging at home, according to the findings of study bade by C. Cochero.

P_{min} is the minimal required charging power, either dictated by the minimal charging current (6A) [8] in case of continuous charging scenario or set to 0A in the case of off-on scenario.

P_{max} is the maximal charging power, dictated by the charging station. Various charging powers will be analysed in different scenarios.

P_{tot} is the total available erasure capacity, the constraint is dictated by market rules.

Meaning that the vehicle will only charge the required amount of energy, given in the driving patterns and that the power of charging needs to be in between technological and regulatory bounders. The minimal charge will be tested in the scenarios to observe limitations of continuous charging.

7. Results and Discussion

This subchapter aims to present the motivation behind the scenario analysis, as well as the final results of the optimisation for a fleet of one thousand electric vehicles. Furthermore, a more detailed look at the most interesting scenarios is presented.

Additionally, the chapter offers a deeper understanding of benefits and constraints of most extreme scenarios. That analysis will result in a clear understanding of key factors and the importance of their impact on the final result for the aggregator.

7.1 Scenarios presentation

The author has selected three key parameters against which the results are tested. The results are tested against following criteria:

1. Target group for an aggregator (either office fleets charged at the office or private EVs of individuals charged at home).
2. The power of the charger.
3. The requirement for minimal charging current.

The outcomes of scenarios analysis will be analysed to answer a question, which out of the three criteria, has the biggest economic value for an aggregator as well as the biggest environmental value. Following scenarios, of presented criteria, will be analysed:

1) The place and pattern of charging.
    a) All of the cars charge at the office.
    b) All of the cars charge at home.
2) The power of the charger.
    a) Charging power of 3 kW.
    b) Charging power of 7 kW.
3) The requirement for minimal charging current.
    a) Continuous charging with the minimal current of 6 A.
    b) Charging could be discontinuous.

To analyse and better understand the influence of each factor all possible combinations of factors are created in scenarios. All of the scenarios will be analysed and briefly presented, however only most interesting scenarios will be presented in detail for the reader.

The reader will be presented with data on environmental and economic impact of each scenario. Furthermore, more detailed information presenting the pattern of capacity reduction along with the demand of erasure and the numbers of available vehicles, will be presented for most interesting scenarios.

7.2 Overview of results

Results of the optimisation were obtained in a CSV format, and later analysed with usage of MS Excel and Tableau for the visualisation of data. The optimisation provided the author with knowledge of daily revenues, as well as knowledge of charging power of each slot of EVs, cumulative power reduction, available EVs and reduced CO_2 emissions in the 5 minutes intervals. To assure that the optimisation is working correctly the author also created the CSV file presenting the percentage of energy charged relative to energy required for each slot of cars.

In this subchapter the reader will have a chance to get accustomed with general results of the scenario analysis. The results consist of economic and environmental analysis. Therefore, factors presented hereunder are taken into account:

- Revenues per car per year.
- Annual revenues.
- Total saved kg of CO_2 due to the capacity erasures created by the aggregator.

The results allowing to compare performance corresponding to the previously mentioned factors of each scenario are presented on the following graphs. Annual Revenues are presented on Figure 21, the revenues per car is presented on Figure 22, while the annual CO_2 savings are presented on Figure 23.

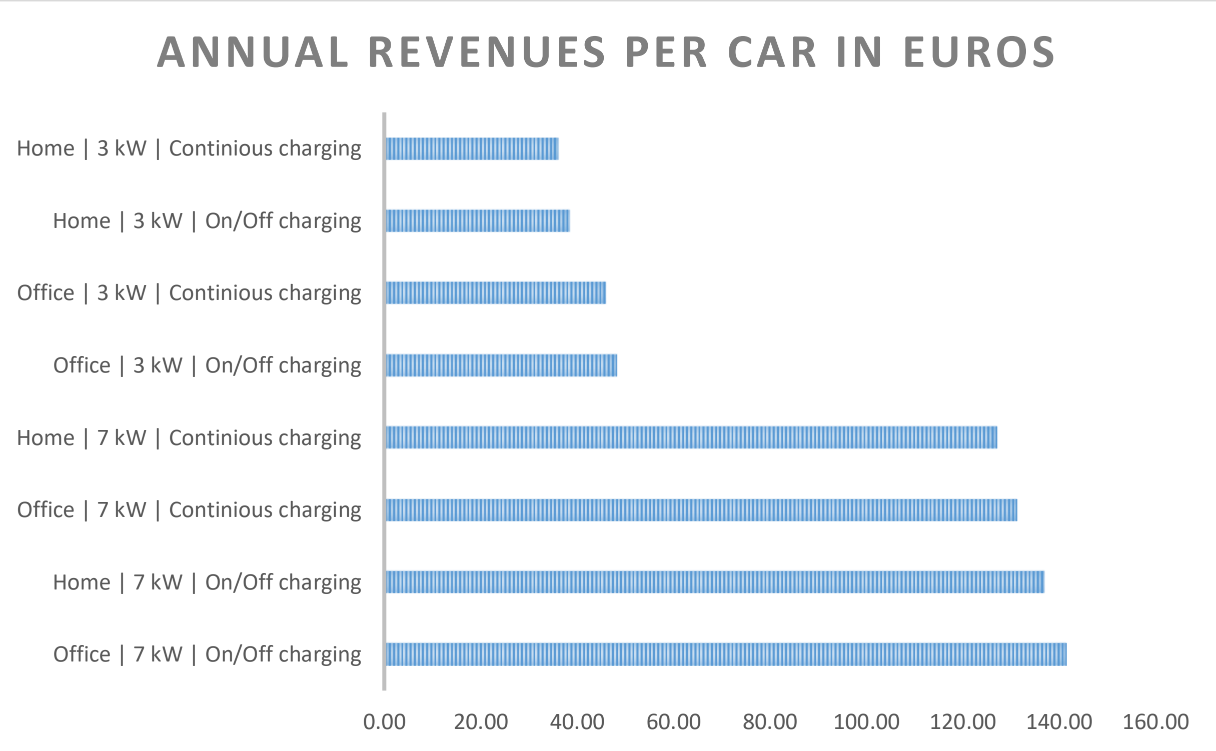


Figure 21 Annual revenues per one EV for each analysed scenario

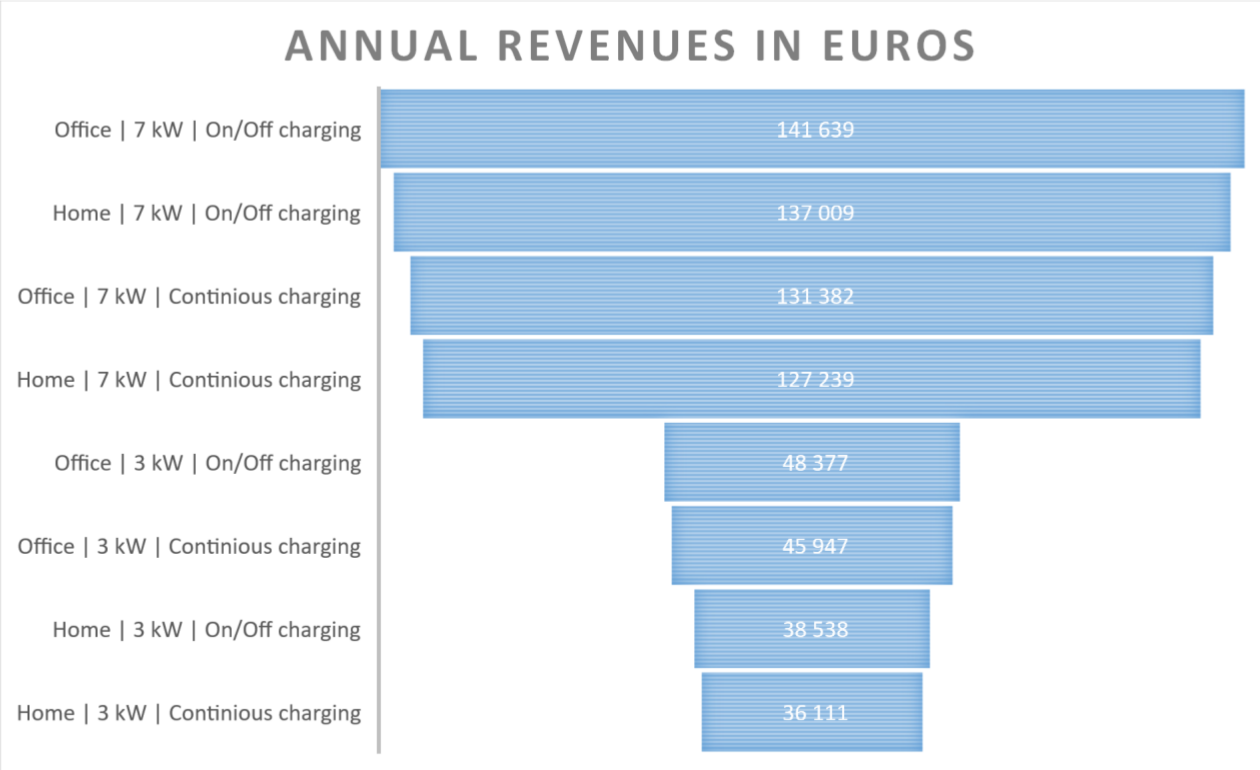


Figure 22 Annual revenues for each analysed scenario

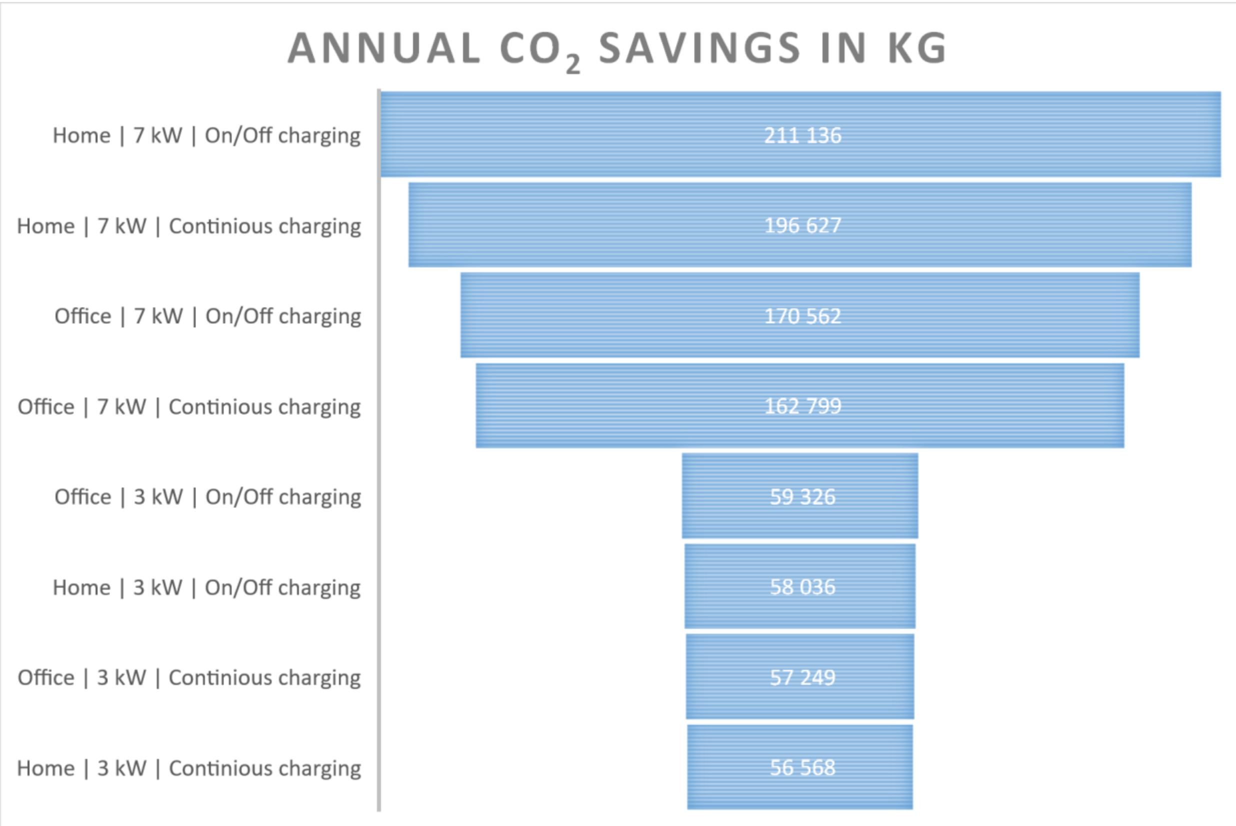


Figure 23 Annual CO_2 savings for each analysed scenario

The results show that the most profitable scenario is discontinuous office charging with chargers of 7 kW power, while the least profitable is continuous home charging with chargers of 3 kW power. The least profitable scenario is also the scenario with lowest CO_2 emissions savings.

However, the most profitable result is not the most environmentally beneficial one. The result that provides most CO_2 emission savings is discontinuous charging at home with chargers of 7 kW power. The difference is caused by the pricing scheme. As more office vehicles are connected during the peak hours, at which the erasure is more profitable, the revenues are higher even if the total erased capacity correlated with CO_2 emission savings, is lower.

Therefore, the author decided to present more detailed version of the results only of those three most interesting scenarios:

- Most profitable: Discontinuous charging at the office with 7 kW charger.
- Most CO_2 emissions savings: Discontinuous charging at home with 7 kW charger.
- Least profitable and least CO_2 emissions savings: Continuous charging at home with 3kW charger.

Additionally the required energy state of charge is presented on the figure hereunder, for the whole fleet for one day, so that the reader could see the difference in the charging process dependant on the time of day the car is connecting (various colour on the figure). The figure also proves that all the cars managed are fully charged at the end of the process.

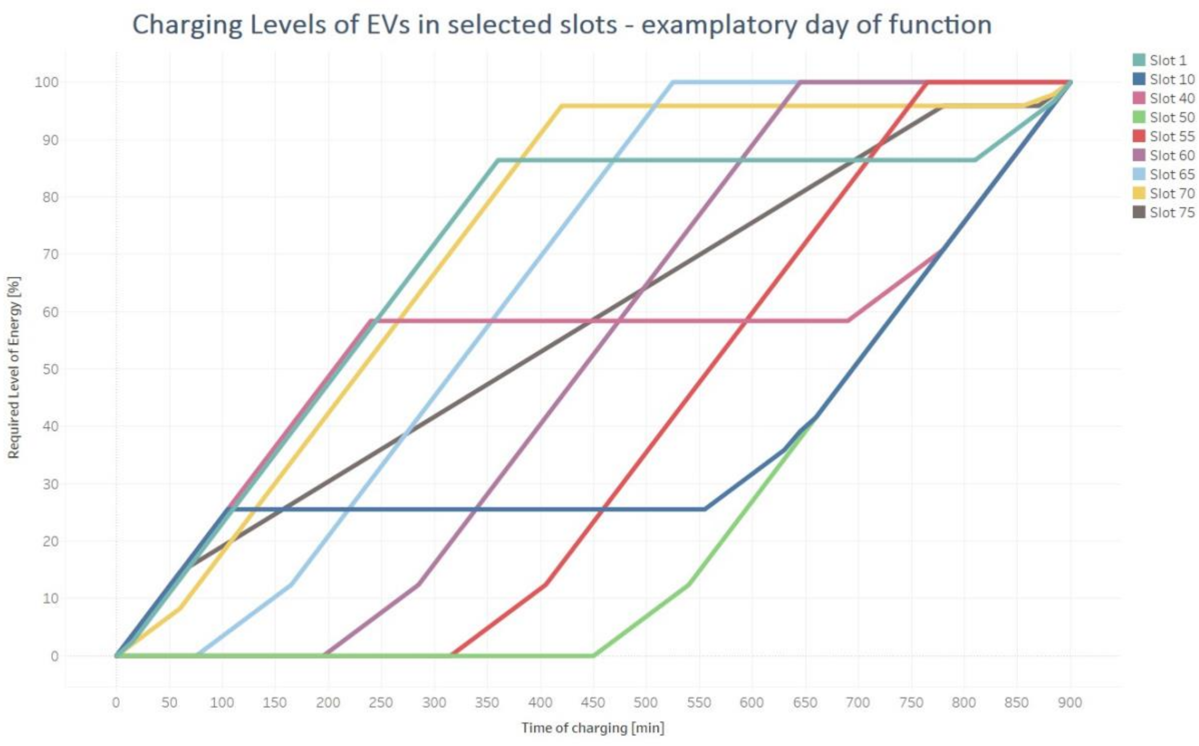


Figure 24 Charging Levels of EVs in each slot - exemplary day of function [%]

7.3 Discontinuous charging at the office with 7 kW charger

Targeting people charging at the office with 7 kW chargers and doing it discontinuously has proven to be most profitable for an aggregator, providing revenues as high as 141 € per car annually. Additionally, actions taken by the aggregator could be perceived as environmentally friendly as they would lead to 170 562 of kg of CO_2 emissions saved each year. More concrete and detailed information of the scenario are presented in this subchapter.

Firstly, an overview of the entire year is presented on the picture on Figure 25.

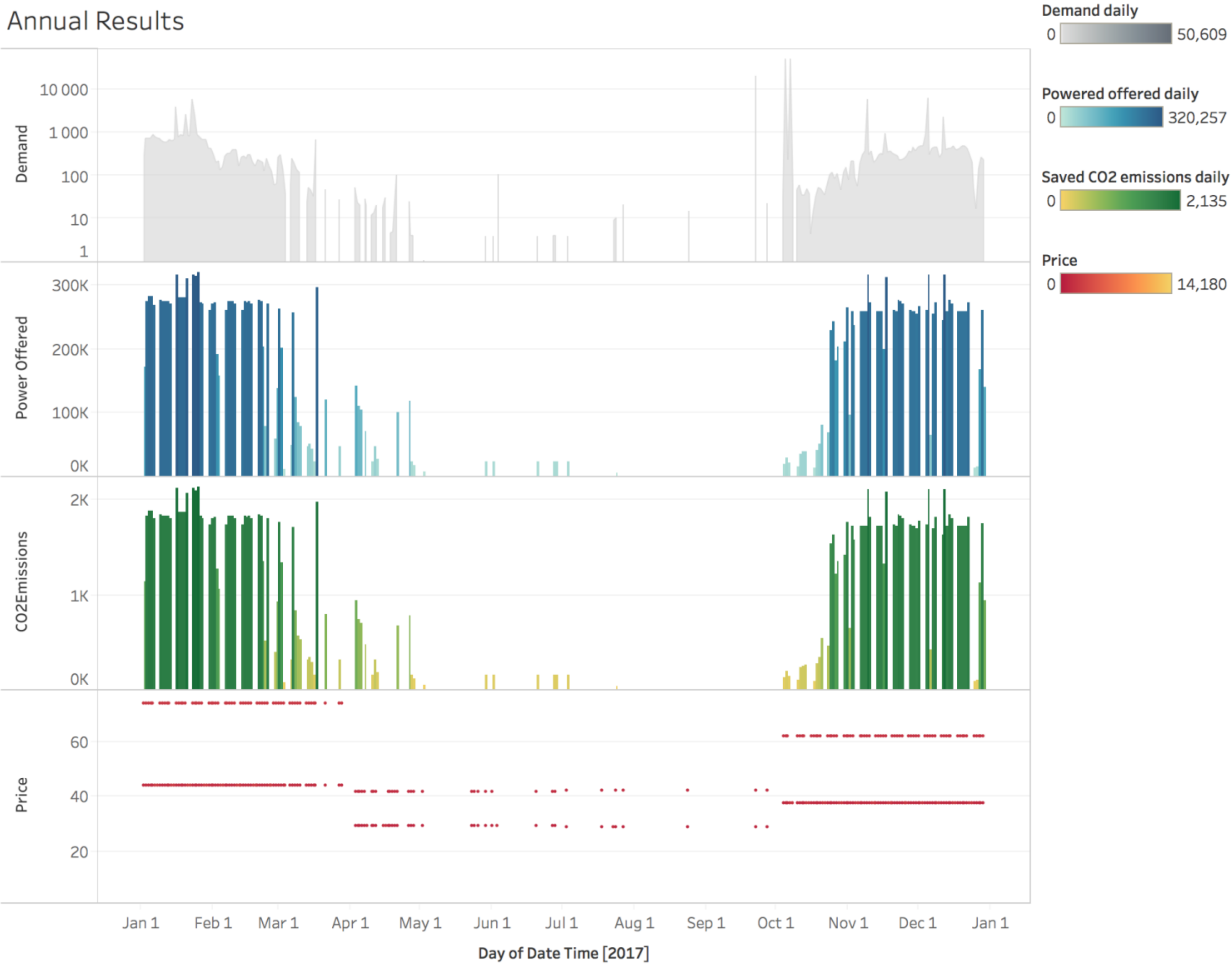


Figure 25 Annual Results of most porfitable scenario

The picture presents the sum of daily demand for the erasure service for 2017 in grey. The daily sum of powered offered is presented in blue and the daily sum of CO_2 emissions avoided is presented in green. The price is also presented for each day. The reader will notice that each day has two prices, in line with the pricing scheme providing base and peak price, except for weekends during which there is only base price. Additionally, the price changes with seasons as the subchapter pricing scheme 3 already established.

The reader can clearly see that the most demand, and therefore offered erasures, appears during the first and fourth quarter of the year. The demand of NEBEF during summer is noticeably smaller, or during some days even non-existent. The reader can also see breaks in powered offered each five days, as the vehicles charging at the office would not be connected during the weekend, according to the previously given car charging scheme. Avoided CO_2 emissions are correlated to the Offered Power, as they are directly related.

Furthermore, the daily scheme, of randomly chosen day of March 17th, showing how the optimisation works is presented hereunder on Figure 26.

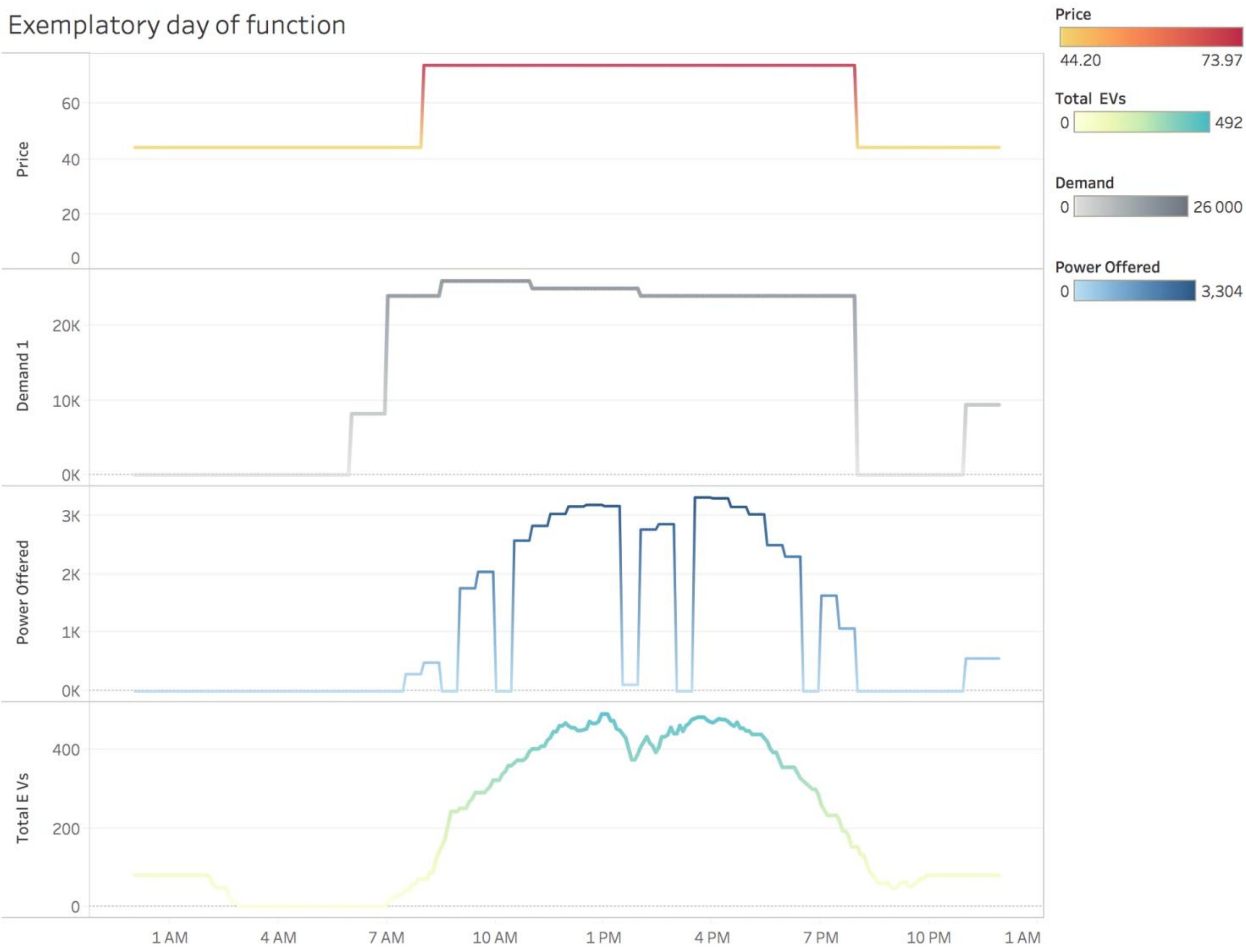
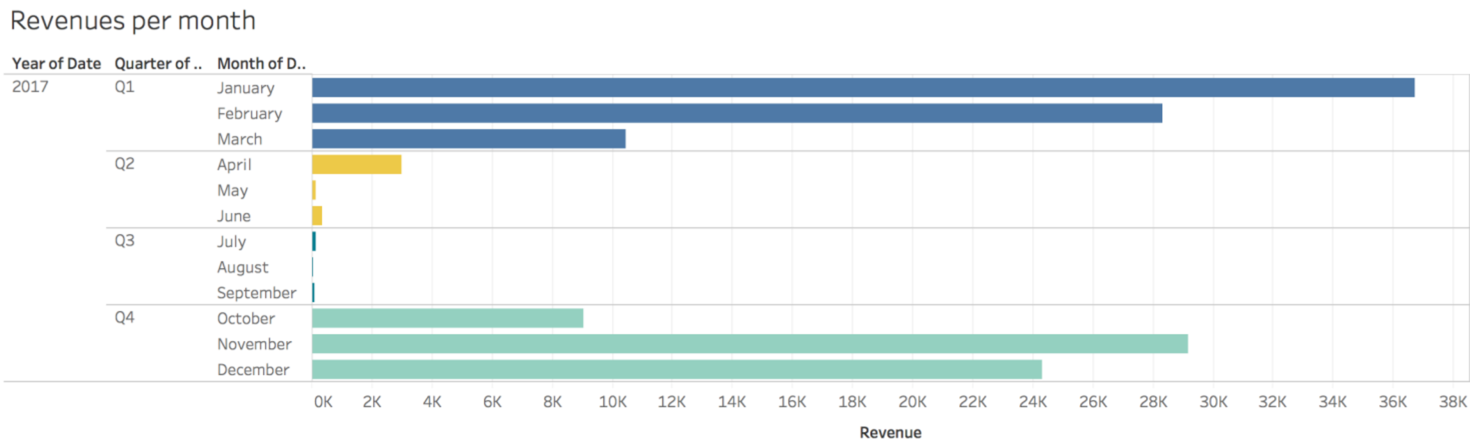


Figure 26 Exemplary day of function of most profitable scenario

The reader can observe the changing daily price (first picture), the daily demand for capacity erasure in kW (in grey), the available power to offer (in blue) and the number of electric vehicles connected and available to manage throughout the day (on the last picture).

It is visible that most of the erasure happens when the price is high, to maximise the profits, which is in line with the amount of available vehicles, proving that the written optimisation is working correctly.

Lastly, a review of annual revenues is presented on Figure 28 describing the most profitable scenario.



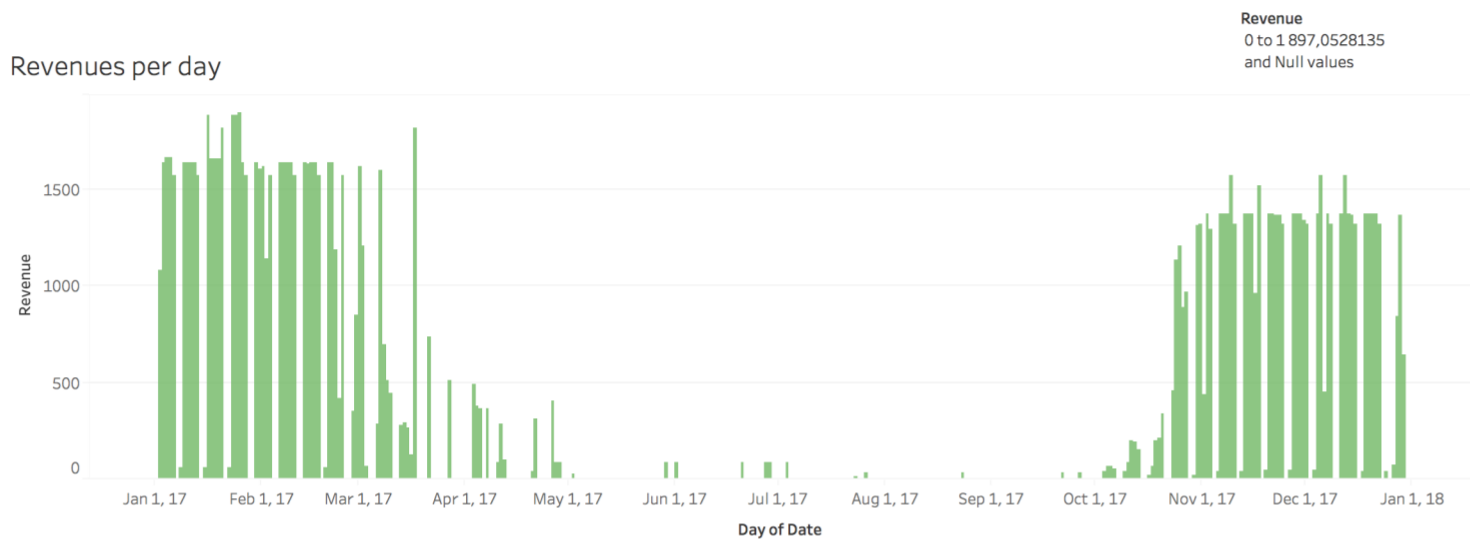


Figure 28 Spread of revenues in the most profitable scenario

The reader can see that the revenues are highest in the first and fourth quarter, when the demand for the erasure is meaningful. The revenues over the summer are marginal, as there is almost no demand in the NEBEF mechanism. The highest revenues are made in January, as high as 37 000 €, the second most profitable month is November providing 28 000 €. Those two months combined make for 46% of overall yearly revenues. As mentioned before, the scenario is the most profitable one securing 141 € per car per year.

7.4 Discontinuous charging at home with 7 kW charger

Targeting people charging at home with 7 kW chargers and doing it discontinuously has proven to be most beneficial for the environment, providing savings in CO_2 emissions as high as 211 136 of kg of CO_2 saved annually. Additionally, the scenario is also one of the most profitable for the aggregator, securing only roughly 5 000 € less of profit than the most profitable scenario. In that case the aggregator could look at 137 € of revenues per year per car.

An overview of the entire year is presented on Figure 29 hereunder.

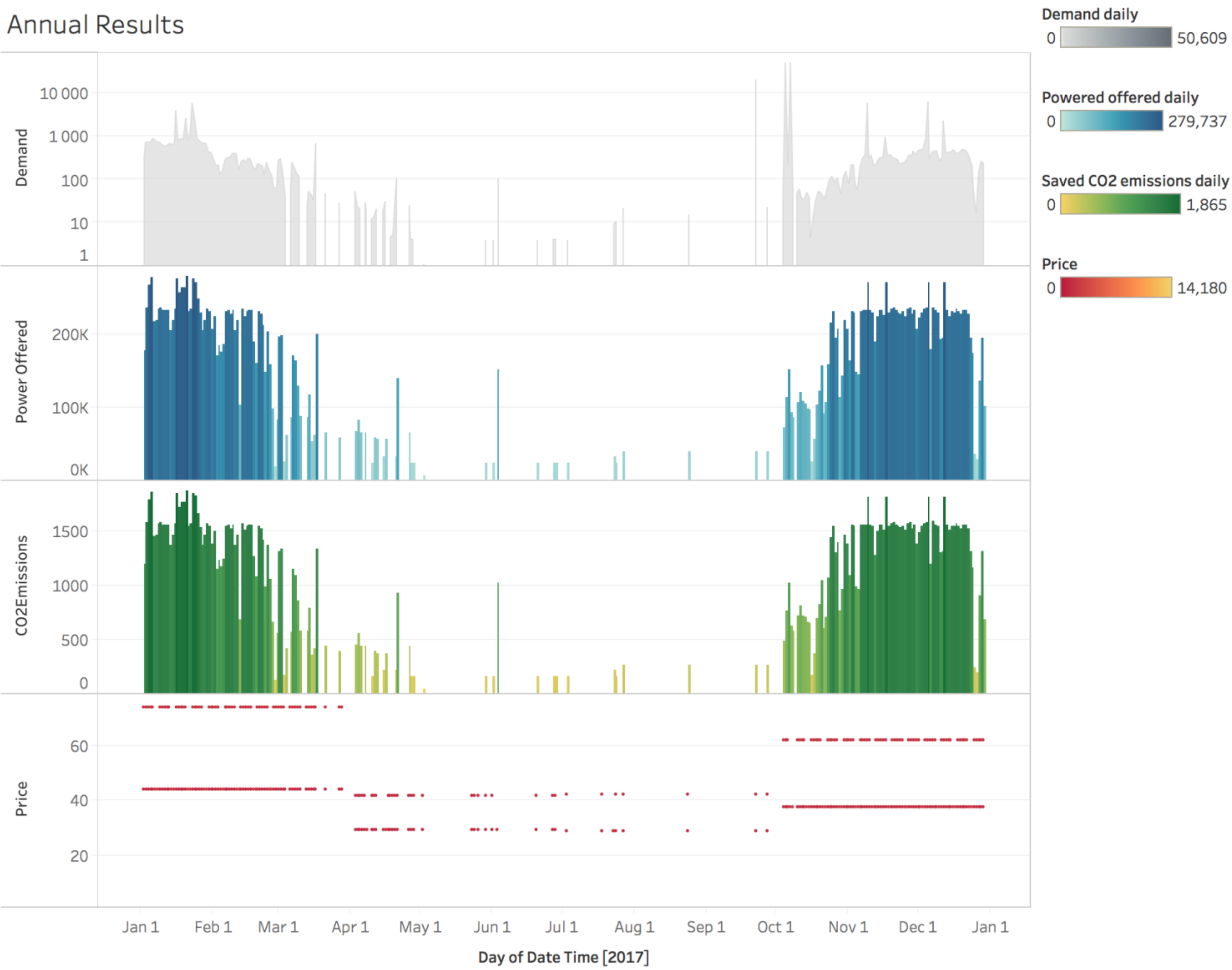


Figure 29 Annual Results of the most CO_2 efficient scenario

The layout of the data visualisation is the same so the layout in the previous case, and will not be discussed further.

The scheme of demand is the same, as the same data for 2017 demand was used, however in this scenario the reader can observe erasures all week long, as home charging clients are also plugging their vehicle during the weekends.

The next figure, Figure 30, presents the daily scheme, of randomly chosen day of March 17th, showing how the optimisation works.

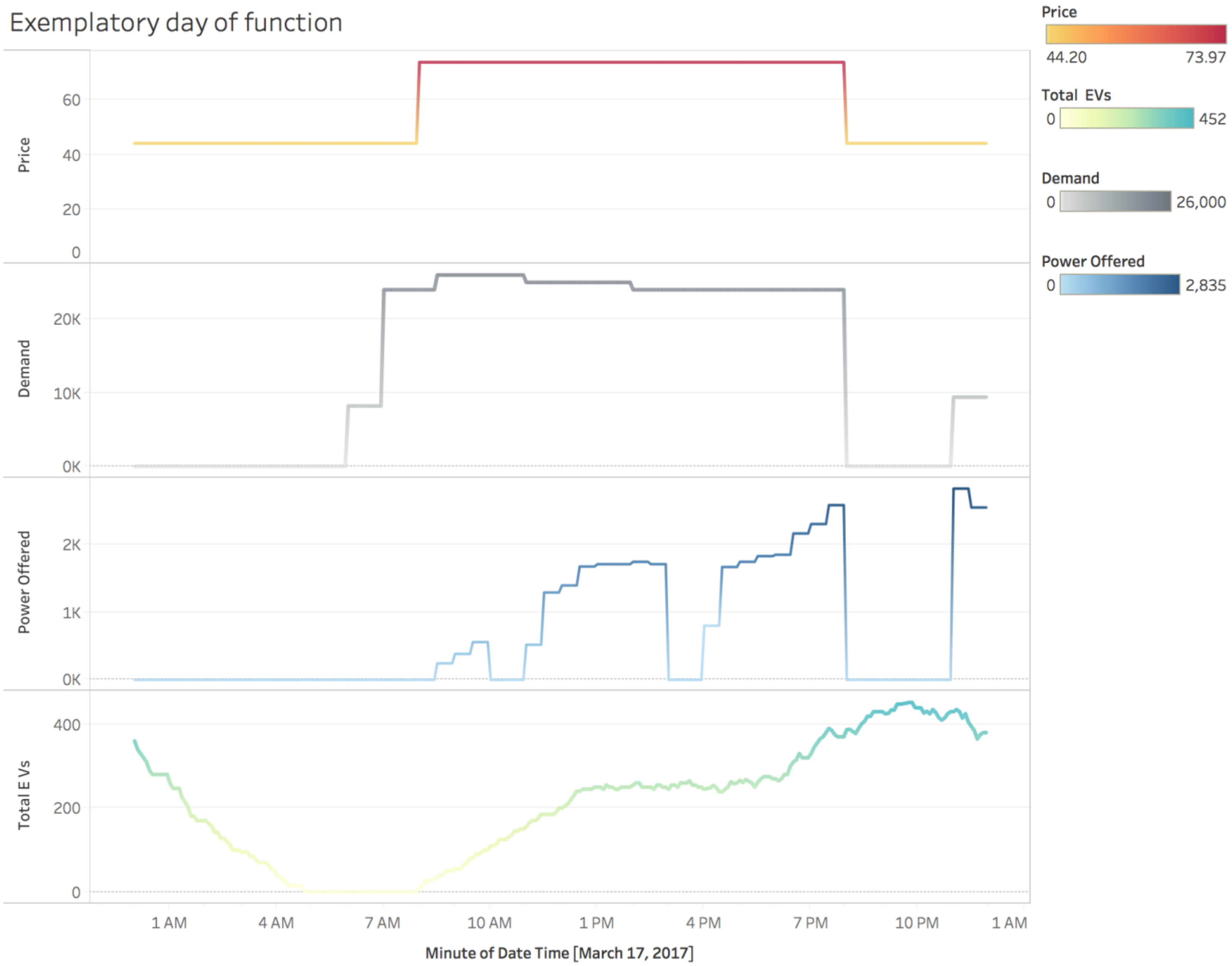


Figure 30 Exemplary day of function of most CO_2 efficient scenario

The reader can observe the changing daily price (first picture), the daily demand for capacity erasure in kW (in grey), the available power to offer (in blue) and the number of electric vehicles connected and available to manage throughout the day (on the last picture).

It is visible that most of the erasure happens when the price is high, to maximise the profits. However, the availability of vehicles is different here, with a lot of vehicles being available in the evening and throughout the night, when the lower price is in operation. Whence, the higher CO_2 emission erasure (higher sum of overall offered capacity), with the lower revenues.

Lastly, again the monthly and daily revenues are presented hereunder on Figure 31.

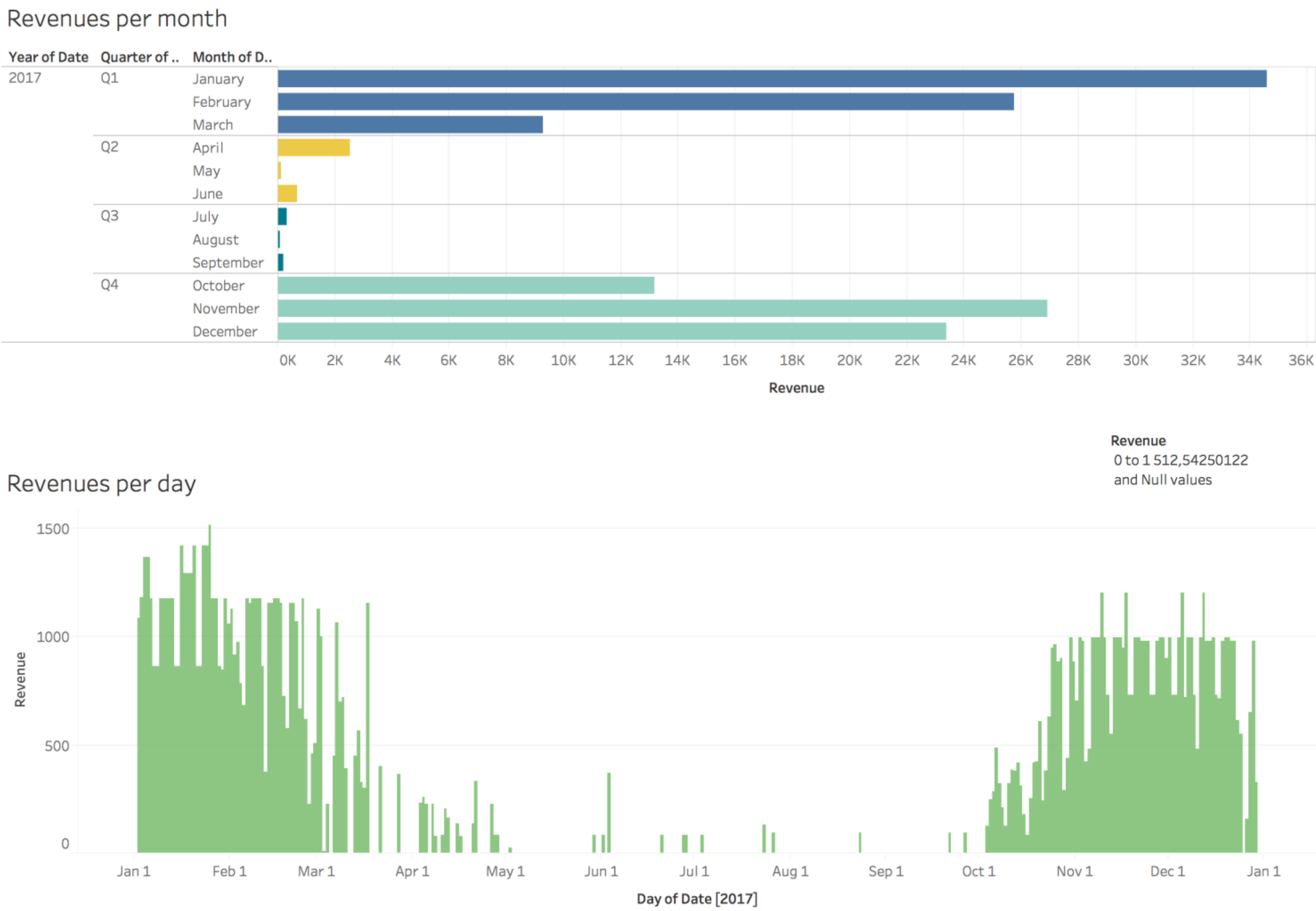


Figure 31 Spread of revenues in the most CO_2 efficient scenario

The reader can see that the revenues are highest in the first and fourth quarter, when the demand for the erasure is meaningful. The revenues over the summer are marginal, as there is almost no demand in the NEBEF mechanism. The revenues are also comparable with the most profitable office scenario, securing almost 35 000 € in January and almost 27 000 € in October. Those months again, make a liens share of 45% of annual revenues of an aggregator. The first scenario was less than 5 000 € more profitable than the second scenario, which secured 137 € of revenues per car annually.

7.5 Continuous charging at home with 3kW charger

Targeting people charging at home with 3 kW chargers and doing it continuously has proven to be the least beneficial scenario for the aggregator. Those results are twofold. Firstly, this scenario was least beneficial looking at the environment, providing 56 568 of kg of CO_2 saved annually, which is just 26 % of CO_2 savings established in the most fruitful scenario in that manner. Additionally, the scenario is also the least profitable for the aggregator, securing only 36 111 € annually, which is roughly a quarter of the revenues offered in the most profitable scenario. In that case the aggregator could look at 36 € of revenues per year per car.

Firstly, an overview of the entire year is presented on the following Figure 32.

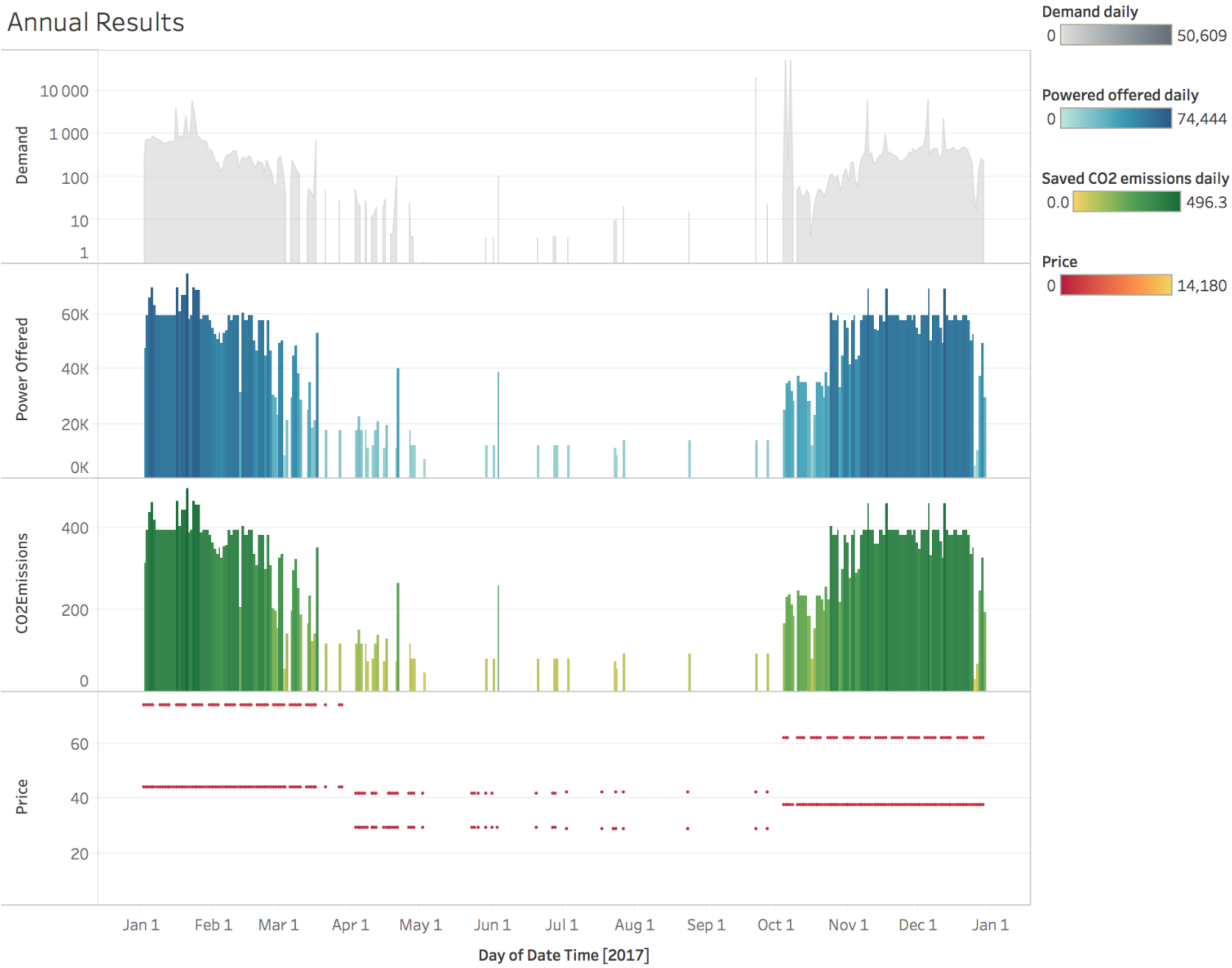


Figure 32 Annual Results of the least profitable and least CO2 efficient scenario

The layout of the data visualisation is the same so the layout in the previous cases, and will not be discussed further.

The scheme of demand is the same, as well as the price scheme is the same as in previous two scenarios. As the targeted client is charging at home, the erasures are done both during working days and weekends. However, the magnitude of Offered Power is noticeably smaller, peaking at 80 kW, which is a quarter of the peak power offered in the first considered scenario. That is because, with 3 kW chargers there is less available charging flexibility.

Figure 33 presents the daily scheme, of randomly chosen day of February 22nd, showing how the optimisation works on a daily basis.

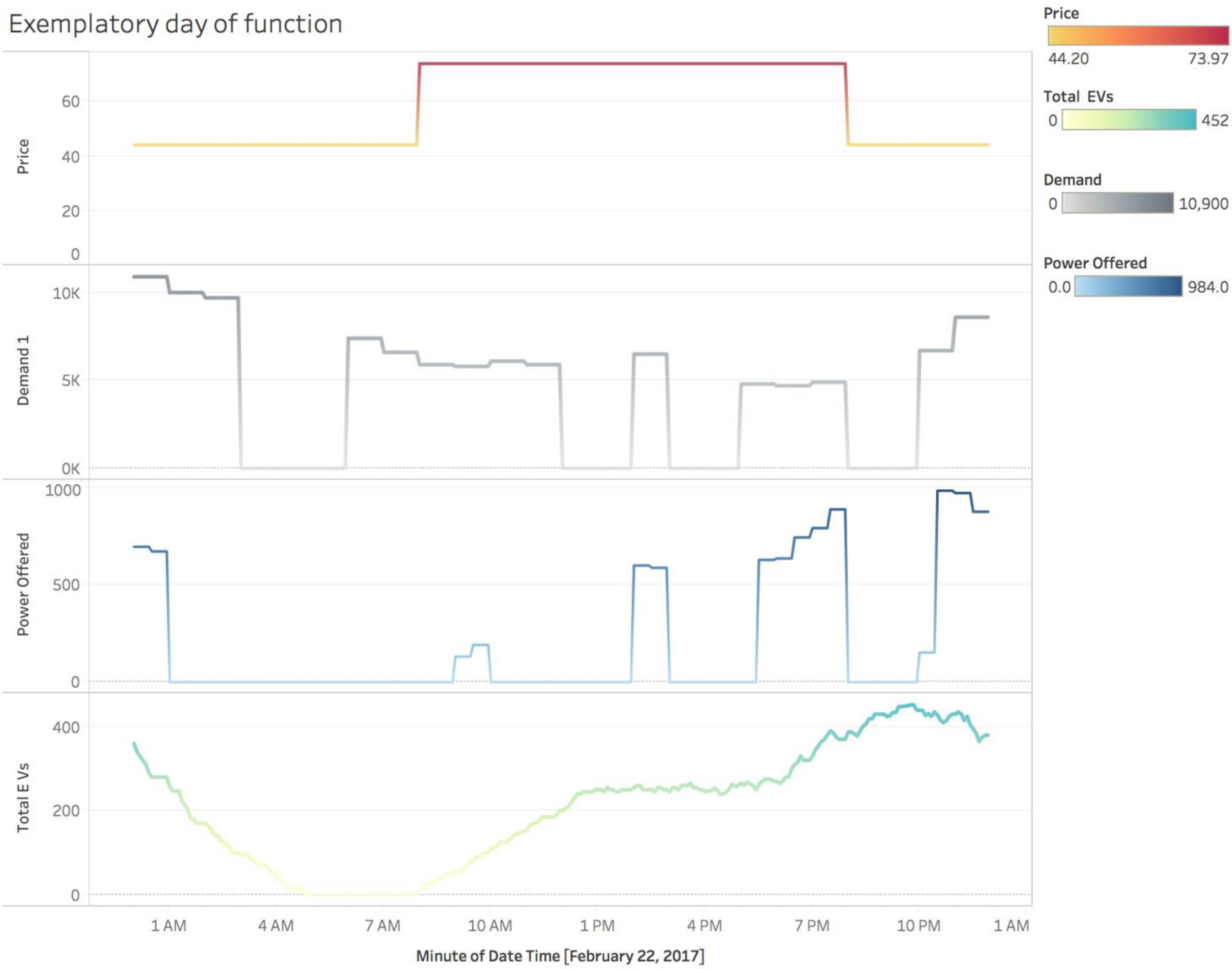


Figure 33 Exemplary day of function of the least profitable and least CO2 efficient scenario

The layout of the data visualisation is the same so the layout in the previous cases, and will not be discussed further.

It is visible that most of the erasure happens when the price is high, to maximise the profits. However, the majority of vehicles is in the evening and throughout the night, when the lower price is in paid for the service of erasure. Together with low levels of flexibility available with 3 kW chargers, that scenario is proving to be the least profitable.

The detailed information of the revenues is provided on the following Figure 34.

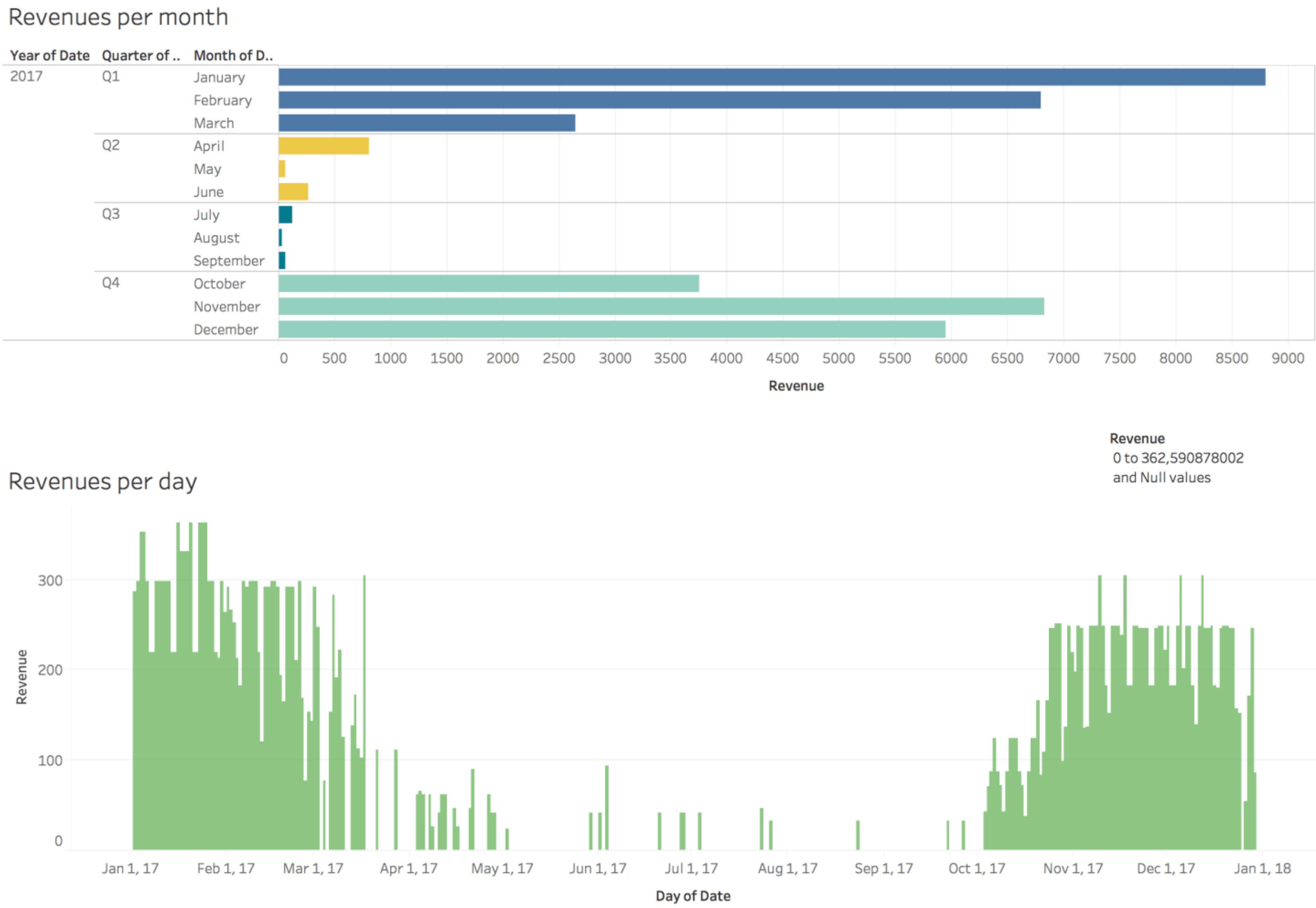


Figure 34 Spread of revenues of the least profitable and least CO2 efficient scenario

The reader can see that the revenues are highest in the first and fourth quarter, when the demand for the erasure is meaningful. The revenues over the summer are marginal, as there is almost no demand in the NEBEF mechanism.

The revenues are not comparable with previously discussed scenarios, securing a quarter of what the most profitable scenario would bring to the aggregator. In this case the aggregator could look at just 36 € of revenues per car annually.

7.6 Influence of various factors

The purpose of this subchapter is to establish which factor has the most influence over the stream of revenues and potentially saved CO_2 emissions. The factors that will be analysed are:

- The targeted group of clients (office chargers or home chargers)
- The power of the charger
- Charging style: either continuous or discontinuous

The impact of each factor will be established based on previously presented results. The results of two similar scenarios, which would differ in the studied factor will be analysed, giving as a result the importance of each factor.

7.6.1 The influence of targeted group of clients

Firstly, the importance of targeted group of clients will be established, to determine whether targeting either people who charge at the office or at home would make an impactful difference in profits.

After the analysis, the author concluded that the stream of revenues is not meaningfully affected by the targeted group of clients. The stream of revenues for those charging at home is on average 88% of those charging in the same manner at the office.

The difference is more meaningful with the 3 kW chargers: 79%, than in the case of 7 kW chargers: 96%.

Looking at the savings of CO_2 emissions, charging at the office established on average 91% of emission savings that charging at home brings.

All in all, both the difference in the stream of revenue and in the potential CO_2 savings are not considered to be significant in the case of changing the targeted group.

7.6.2 The influence of power of the charger

Secondly, the importance of power of the charger that is being used will be established, to determine whether the change of charging power would create a significant difference in the stream of revenue and potential CO_2 savings.

After the analysis, the author concluded that the power of the chargers changes the stream of revenues meaningfully. Using a 3 kW charger, brings on average 31% of revenues, compared to usage of 7 kW charger. That is understandable, as the amount of available flexibility of charge, and as following offered power is lowered drastically with the change of the charger power.

Looking at the savings of CO_2 emissions, the difference is also major, as the power available to offer is lower. Again switching to 3 kW chargers lowers the potential CO2 savings on average to 31% of those achievable with 7 kW chargers.

To conclude, both differences are of huge significance to the aggregator. Therefore, it would be recommended to target the owners of higher powered chargers.

7.6.3 The influence of the method of charging

Lastly, the importance of the method of charging will be established, to determine whether the aggregator should offer preferred by clients continuous charging or should charge the vehicles discontinuously. The analysis will show whether the change would create a significant difference in the stream of revenue and potential CO_2 savings.

After the analysis, the author concluded that the method of charging does not affect the stream of revenues significantly. Charging continuously brings on average 94% of revenues achievable with charging discontinuously.

Looking at the savings of CO_2 emissions, the difference is not drastic also. Again continuous charging would save 96% of CO_2 that discontinuous charging could potentially save.

Concluding, the stream of revenues and the potential CO_2 savings are not majorly affected by the method of charge, as previously supposed the author.

Overall, the most significant factor that the aggregator should be considering is targeting the owners of higher powered chargers: 7 kW, compared to 3 kW. Moreover, the aggregator could freely distribute their fleet between office and home chargers, as the targeted group does not bring a dramatic change in revenues. Furthermore, the aggregator could choose to use the preferred by users continuous charging method without drastically changing its stream of revenues and environmental impact.

8. CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

The purpose of this paper was to present the study of feasibility and market analysis of EV scheduling and aggregation on European Markets.

The first part of the study consisted of a market analysis on the side of TSO's regulations in regard to DSR and aggregation, as well as the side of EV market assessment and potential growth of EV fleets in chosen prospering markets.

The second part of the study was rather practical and contained creating an algorithm allowing to assess potential economic earrings and CO_2 emissions savings related to balancing the grid with EV charging scheduling and aggregation on a chosen market: NEBEF balancing mechanism in France.

The author has found that the major constraint for balancing the grid through smart charging in Europe is the regulatory state in terms of DSR and aggregation of majority of European countries. The greater part of EFTA countries either do not mention DSR and aggregation in their regulation or create constraints making it impossible for a third party aggregator to join the markets.

The author found that the markets that could be potentially open to grid balancing with smart charging are those available in the UK, France, Belgium Switzerland and Finland. However, this is a revolutionary time for the aggregation and DSR regulations, as numerous countries have expressed an interest in changing their regulations to encourage those actions. The examples of the counties that could be potentially open for a third part aggregator in the near future are: Ireland, Estonia, Sweden, Denmark, Norway, Germany and Poland.

Nevertheless, singularly the regulations consent for third party aggregator to enter an play on the market is not enough for the grid balancing with EV smart charging to function, as the EV market in the considered location should already be blooming to gather the first clients, and aggregate a meaningful capacity. Out of the pool of markets that allow DSR and aggregation, the author found, that best functioning EV markets, in terms of number of vehicles and available chargers are those of France and UK. Furthermore, the EV market in all of the previously listed countries is expected to grow rapidly, so the aggregator could consider joining those markets in the years to come.

Looking at the following part of the paper, the author choose to further analyse the French NEBEF balancing mechanism market over any of the UK market. That was because the data available for the UK STOR market, which was the other one considered, was in a form of a yearly summary of the market. Therefore, the author decided to analyse NEBEF which publishes all needed data in the interval of 30 minutes.

Moreover, the author has considered three key changing variables in the scheme of charge, those were: the targeted group of clients, either charging at home or at the office, the power of the used charger, either 3 kW or 7 kW and the scheme of charging, either charging discontinuously, meaning switching the charger on and off, or charging continuously with the constraint of minimal current.

Through the algorithm, the author has found that the most important factor, significantly changing the stream of revenues for the aggregator, is the power of available chargers, as it could lower the revenues by as much as 70%, while comparing 3 kW chargers to 7 kW chargers.

The other remaining factors did not have such strong influence over the stream of revenues, targeting home chargers would provide 90% of the revenues that targeting office chargers could. Additionally, using the continuous charging method, rather than discontinuous, only lowered the revenues by 5%.

The stream of revenues was the highest in the case of discontinuously charging with office chargers of 7 kW, while the potential CO_2 savings where the highest in the case of charging discontinuously at home with 7 kW chargers. That is because most of EVs charging at home were connected to the charger during night hours when the price for the erasure service was lower. Therefore, even though a total erased power offered was higher the stream of revenues was lower. The difference, however was marginal: 3,5%.

The revenues of an EVs aggregator available on the NEBEF mechanism, proven to be over the initial expectations, and as high as 141 € per car annually. While the potential emission of CO_2 savings could reach 211,136 kg per car annually.

8.2 Future work

The next stopes would be also twofold. First of all an ever constant analysis of changes in regulations concerning aggregation and demand side response should be done for all the European markets.

Secondly, the algorithm could be used to analyse the returns from using middle powered chargers of 22 kW capacity. Moreover the author concluded that an interesting scenario to analyse would be that of combined home and office chargers fleet, to see how the distribution of EVs controlled by the aggregator would look like.

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Another key activity would be to try to obtain more concrete data for UK STOR mechanism, prepare the data to feed it to the algorithm, and analyse results. That would present a more clear vision for the aggregator on the market that should be more appealing.

8.3 Final note

During writing of the paper the author has found that the concept of grid balancing with smart EV charging could not, most likely, be implemented successfully on the European scale because of current regulatory constraints concerning aggregation and demand side response. However, the author truly believes that this innovative and sustainable solution will soon be present in our day to day lives.

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